Integrating Local Weather Forecast Knowledge into Weather and Climate Information Services

A study in Narok North, Kenya

MSc Thesis by Lianne Sänger

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Master Thesis Earth Systems and Global Change in partial fulfilment of the degree of Master of Science in International Land and Water Management at Wageningen University & Research, the Netherlands.

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Abstract

Small-scale rainfed agriculture is the primary economic activity in Kenya and the sub-region of Narok North, making the area and its farmers highly vulnerable to climate change. Access to accurate weather information, which can be derived from both local and scientific forecasts, is essential for making climate-sensitive agricultural decisions, particularly for rainfed agriculture. This study investigates the role of local weather forecasting knowledge in Narok North, focusing on documenting the use of ecological indicators by smallholder farmers in Kenya and Narok North. Furthermore, it explores smallholder farmers' experiences with and the potential of the DROP app, a weather and climate information service that integrates this local knowledge in Narok North. The results indicate that farmers in Kenya and Narok North employed a wide variety of local weather forecasting indicators, with meteorological and animal indicators being predominant. Most of the indicators focused on clouds and wind, as well as the movements and sounds of birds, insects, and other animals. Astrological, plant, and other indicators were used less frequently. In Narok North, smallholder farmers heavily relied on local weather forecasting knowledge, with ecological indicators and the local weather calendar serving as key sources of weather information, while scientific forecasts were employed less often. Experiences with the DROP app, which integrates this local knowledge, were generally positive. Farmers found the app's forecasts to be accurate and useful for their climate-sensitive agricultural decision-making, although challenges with internet access persisted. Both farmers and key informants suggested that integrating local knowledge enhances the understanding, accuracy, and credibility of the forecasts. Given that local weather forecasting indicators are widely used among smallholder farmers and that they heavily depend on local knowledge as a source of weather information in Narok North, there is significant potential for the DROP app in this region. By combining local and scientific knowledge, this hybrid weather forecast could increase the uptake of weather information and thereby support agricultural decision-making, assisting smallholder farmers in adapting to rainfall variability induced by climate change.

Key words

Small-scale Agriculture – Weather and Climate Information Services – Hybrid Weather Forecasting – Local Knowledge – Ecological Indicators – DROP app - Kenya

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List of Abbreviations

WCIS: Weather and Climate Information Service

LK: Local Knowledge

SK: Scientific Knowledge

LFK: Local weather Forecast Knowledge

SFK: Scientific weather Forecast Knowledge

1. Introduction

The frequency and magnitude of extreme weather events have been increasing in the past decades due to climate change, threatening farmers' livelihoods (Kalele et al., 2021). The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) raises that weather and climate extremes are already visible in the world as a result of human-induced climate change (IPCC, 2023). Scientists have tried to predict and map the future impacts of climate change but effects such as drought and extreme rainfall events are happening faster than expected (IPCC, 2021). The impacts are significantly changing the long-term weather patterns in regions worldwide (Mahato, 2018), affecting the agricultural sector (Akram et al. 2021; Hatfield et al., 2020). The changing climate impacts soil fertility, irrigation, and crop cycles, challenging agricultural systems (Malhi et al., 2021). The growing demand for food amplifies the threat of climate change (Musafiri, 2022).

In addition to affecting food security, climate change poses a challenge to the future of farmers' livelihoods. Changing climatic conditions can cause significant economic losses (Malhi et al., 2021). In Africa, the agricultural sector serves as the primary source of employment and is crucial to combat poverty and hunger (Magesa et al., 2023). Climate change is particularly of great concern in Kenya, where small-scale agriculture is one of the most impacted sectors (Ochieng et al., 2016). Drought, crop disease, and floods affect livelihoods in Kenya by causing food shortages, increasing food crises, and water shortage (Kalele et al., 2021). Given the profound impact of climate conditions on agriculture, it is essential to address these conditions through adaptation strategies. Skilful weather forecasting information is crucial since farmers' agricultural decision-making is based on these projections (Fathi et al., 2022; Roudier et al., 2014). Consequently, weather forecasting is essential for maximizing yield, minimizing crop damage and protecting livestock from extreme temperatures (Sarma & Kakoti, 2024).

Adequate infrastructure for scientific weather forecasting is often lacking in the developing world (Lofstead, 2023). Key barriers in East and West Africa to the adoption of scientific weather information are the limited communication and understanding of (scientific) weather information (Agyekum et al., 2022). Moreover, a lack of access to the area-specific data, insufficient training, inadequate equipment and distrust of the source of the information are key barriers (Agyekum et al., 2022). In the absence of scientific weather forecasting, smallholder farmers in the eastern part of Africa often base their agricultural decision-making on local knowledge (Kumar et al., 2020). Historical weather calendars and ecological indicators are among the main sources of local weather forecasting knowledge (Paparrizos et al., 2023a; Radeny et al., 2019). Predictions based on local knowledge have shown to be more accurate and reliable on a lower spatial scale, i.e. the local level (Nyong et al., 2007). The skill level of local weather forecasting indicators can even compete with scientific weather forecasts (Gbangou et al., 2021). Moreover, local knowledge is vital to social, political, cultural and economic growth in communities (Tanganyika, 2018).

Given the challenges posed by climate change, smallholder farmers need useable climate information to improve climate-sensitive decision-making, such as a weather and climate information service (WCIS) providing tailored weather information (Findlater et al., 2021). WCISs should be tailored to the societal actor, specifically, smallholder farmers practicing rainfed agriculture. A WCIS can be tailored to its users by integrating local knowledge (Radeny et al., 2019). The resulting hybrid forecast benefits from elements of both local and scientific knowledge about weather prediction (Balehegn et al., 2019). According to Radeny et al. (2019), integrating local weather forecasts into a WCIS can increase the trust and willingness of farmers to apply scientific weather forecasts. Hence, recognising and harnessing local knowledge can improve farmers' capacity to deal with climate variability and change (Chengula and Nyambo, 2016). Therefore, integrating local knowledge into a WCIS could improve climate-sensitive agricultural decision-making, enhancing farmers' livelihoods. This study explores local knowledge and experiences with a hybrid weather information service in Kenya, specifically in the sub-region of Narok North.

2. Study area

Kenya is located in the eastern part of Sub-Saharan Africa. Arid and semi-arid zones occupy the majority of the land (GoK, 2019). Agriculture accounts for 52% of Kenya's gross domestic product, making it an important contributor to the country's economic growth (FAO, 2015). Over half of the country's households are involved in agriculture (Ministry of Agriculture & Livestock Development, 2019). The country predominantly relies on rainfed agriculture, making the agricultural systems highly vulnerable to climate variability and change (Radeny et al., 2019), which is why the country was selected as the study area. The great impact on agriculture is also a result of the unreliability of the historical seasonal patterns (Marigi, 2017). Smallholder farmers are aware of climate change and its effects but remain challenged in adapting to it. Musafiri et al. (2022) identify the unpredictability of weather patterns as one of the main barriers to climate change adaptation.

Narok County (Figure 1) is located in the southwest of Kenya within the Great Rift Valley, approximately 150 kilometres west of Kenya's capital city, Nairobi. With a population of over 1.1 million in 2018, Narok County occupies a surface of 18.000 square kilometres (Narok County Government, n.d.). Topographically, the County is divided into lowlands and highlands, with the lowland lying 460 meters above sea level and the highland rising to 3100 meters above sea level (Korir & Ngenoh, 2019). Narok County's bimodal rainfall season has shown short rains experienced from October to December (The Narok County Government, 2023), with an average of 500 mm per year (Korir & Ngenoh, 2019) and long rains from March to May (The Narok County Government, 2023) with an average of 1800 mm per year (Korir & Ngenoh, 2019). However, climate change imposes a shift in climate conditions. Between 1950 and 2007, rainfall declined, and mean temperature increased (Ojwang et al., 2010). Narok County is subject to increasing intensities and frequencies of extreme weather events. Most of these extreme weather events are droughts resulting from delayed rains (Mulenkei, 2015). In the future, the consecutive dry days are expected to increase by four days, while the consecutive wet days will increase by five days, resulting in a risk of droughts and flooding (The County Government of Narok, n.d.).

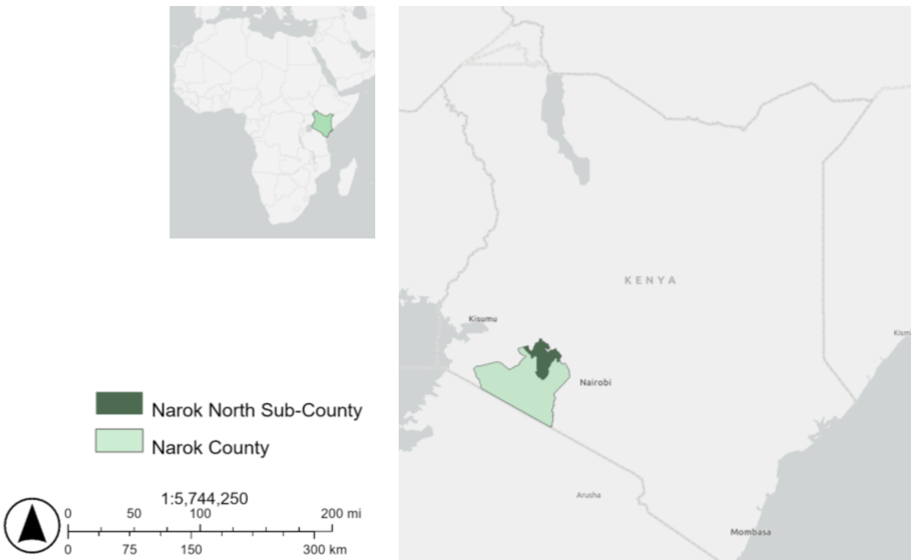

Figure 1 Geographical Representation of the Study Area: Narok North Sub-County highlighted within Narok County in Kenya

Narok North is one of six sub-counties of Narok County. Narok North had a population of approximately 251.180 people in 2019, which is expected to increase in the upcoming years (County Government of Narok, 2023). Narok North covers an area of around 2,603.30 square kilometres (Narok Senate, n.d.) and consists of six wards: Melili, Narok Town, Nkareta, Olokurto, Olpusimoru and Olorropil (Figure 2). The area can be divided into two agrological zones: highlands and lowlands. Narok North is highly dependent on small-scale rainfed agriculture, making farmers vulnerable to climate change. This vulnerability presents an opportunity to build resilience through climate adaptation, making the region suitable for this study. In Narok North, commonly grown crops are Irish potatoes, maize, wheat, beans, barley and horticultural crops. Additionally, livestock, mostly cattle, sheep and goats, is one of the main economic activities (Narok Senate, n.d.).

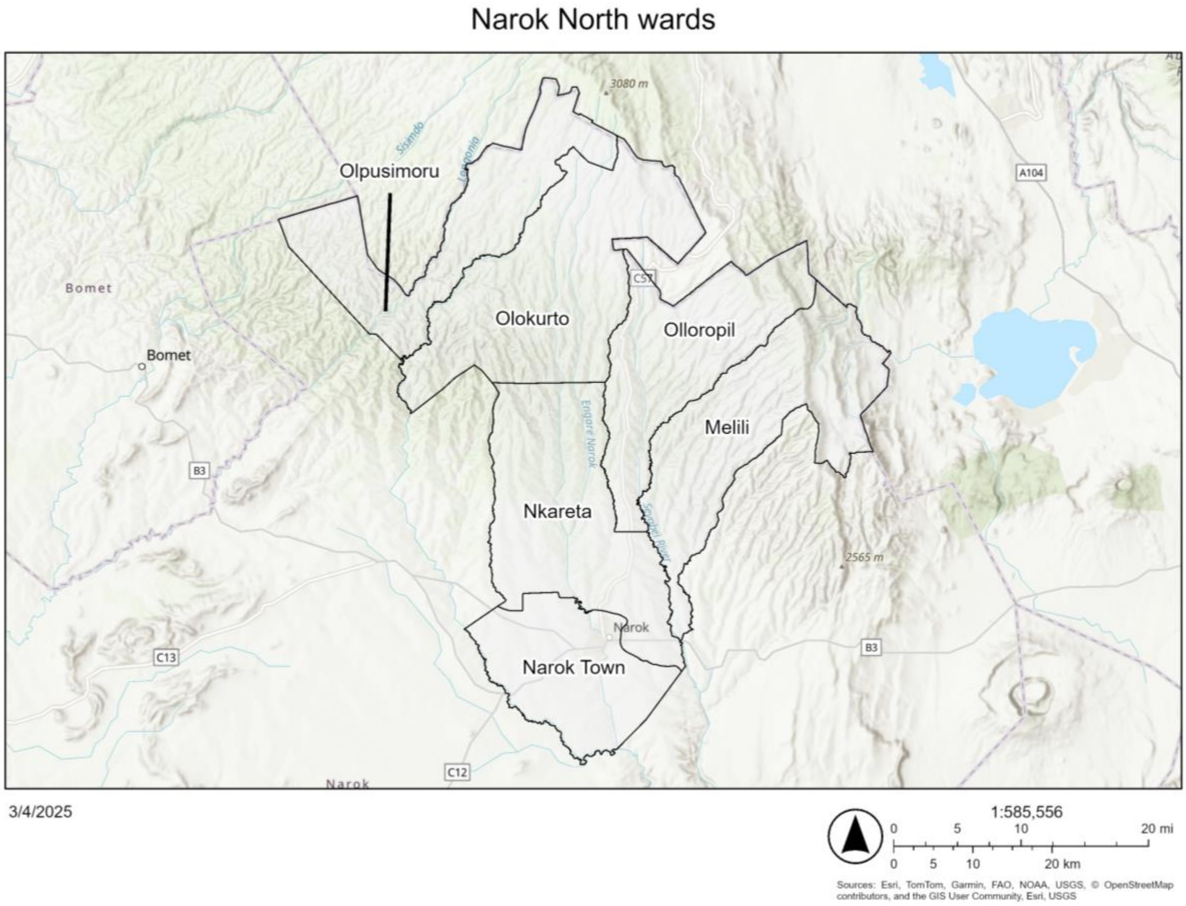

Figure 2 Geographical Representation of the Study Area: Narok North Sub-County illustrating its Six Wards

3. Problem Statement and Research Questions

3.1 Problem Statement

As small-scale rainfed agriculture is the primary economic activity in Kenya and Narok North, agriculture and thus the prosperity of farmers is extremely vulnerable to the effects of climate change (Mukuna, 2013; County Government of Narok, 2023; Salami et al., 2010). Providing timely dissemination of climate information could enhance the capacity of farmers to deal with the changing climate conditions (Kalele et al., 2021; Sarku et al., 2022), sustaining their livelihoods. Many farmers currently rely on local weather forecast knowledge to make agricultural decisions (Gbangou et al., 2021; Kumar et al., 2020; Nyadzi et al., 2022; Paparrizos et al., 2024). Despite this, documentation of local knowledge is lacking (Enock, 2013; Paparrizos et al., 2023a; Radeny et al., 2019). As local weather forecast indicators are used more universally than others, it is vital to identify them (Paparrizos et al., 2024; Radeny et al., 2019), for example, those primarily used in Kenya and Narok North.

A WCIS that integrates local and scientific weather information, the DROP app, has the potential to support farmers' adaptation to climate change, especially when the WCIS is the result of co-production. The inadequate uptake of scientific weather information and resulting limited capacity of farmers in Narok County to cope with climate change (County Government of Narok, 2023) can be tackled by combining local and scientific forecast knowledge (Paparrizos et al., 2024; Sutanto et al., 2024). The resulting hybrid forecast could increase the uptake of WCISs (Gbangou et al., 2020; Gbangou et al., 2021; Nyadzi et al., 2022; Paparrizos et al., 2023b; Paparrizos et al., 2024). Co-producing the WCIS by integrating farmers' local knowledge, the forecast based on ecological indicators, can enhance the understanding and acceptance of scientific forecast knowledge (Paparrizos et al., 2023b), increase the forecasting accuracy (Irumva et al., 2021; Ochieng et al., 2021; Speranza et al., 2010; Plotz et al., 2017) and build credibility and trust (Kumar et al., 2021; Nyadzi et al., 2022; Van der Horst et al., 2022). Since the potential of a hybrid forecasting in supporting agricultural decision-making has received limited attention in practice, it is necessary to explore farmers' experiences with the hybrid forecast and explore its potential in Narok North.

This study answers the call for identifying local weather forecast indicators and for investigating the potential of hybrid forecasting in supporting agricultural decision-making. Concurrently, the aim of this study is twofold: to document the Local weather Forecast Knowledge indicators used by smallholder farmers in Kenya and Narok North, and to explore the potential of a WCIS, specifically the DROP app, to enhance smallholder farmers' resilience to climate change in Narok North.

3.2 Research Questions

Main research question (MRQ): *How can integrating Local weather Forecast Knowledge into a Weather and Climate Information Service, specifically the DROP app, enhance smallholder farmers' ability to deal with climate change in Narok North, Kenya?*

Sub research questions (SRQs)

1. *Which Local weather Forecast Knowledge indicators do farmers use to predict the weather and climate in Kenya and in the sub-region Narok North?*
2. *What is the role of Local weather Forecast Knowledge and Scientific weather Forecast Knowledge in Narok North, Kenya?*
3. What are the experiences of farmers with the DROP app in Narok North, and what potential do farmers see concerning agricultural decision-making?

4. Conceptual framework

4.1 Small Scale Agriculture

There are several definitions of small-scale agriculture. For example, the Food and Agriculture Organisation of the United Nations (FAO) defines smallholder farmers as: "*small-scale farmers, pastoralists, forest keepers, fishers who manage areas varying from less than one hectare to 10 hectares*" (FAO, 2012, p.1). Alternatively, Nyambo et al. (2019) define a smallholder farmer as "*a person involved in farming a small piece of land, cultivating food crops, sometimes with small varieties of cash crops"* (p. 1). The FAO (2012) highlights that smallholder farmers often have family-oriented objectives such as supporting their household, providing labour for their family, and ensuring their food supply. Smallholder farmers are often viewed as having a low economic status and lacking or having limited access to larger agricultural supply chains (Andrade, 2016). A substantial amount of the total food production worldwide comes from smallholder farmers (Lowder et al., 2016). Therefore, they are of great importance in facilitating the transition to sustainable agriculture (Andrade, 2016).

4.2 Weather and Climate Information Services

Vaughan and Dessai (2014) describe climate services as follows: "*Climate services involve the generation, provision, and contextualization of information and knowledge derived from climate research for decision making at all levels of society*" (p.1). A WCIS communicates climate change data, short-term weather forecasts, and the required long-term information on adaptation strategies by making climate data available to its users (World Bank Group, 2016). In other words, WCISs aim to bridge the gap between decision-making and scientific research (Paparrizos et al., 2023c). In the case of agriculture, WCISs could raise awareness of future climate, assisting farmers in mitigating the impact of these climate conditions and thus giving guidance in decision-making (Vaughan & Dessai, 2014).

4.2.1 Two Generations of Weather and Climate Information Services

There are two generations of WCISs. The first generation of WCISs has a top-down approach, where the scientific community creates technologies that facilitate the creation of scientific knowledge and intend to aim for the scientific audience (Paparrizos et al., 2023c). However, this way of providing WCISs can create a usability gap, meaning it is not suitable to successfully inform decision-making due to a lack of tailored information. In contrast, the second generation of WCISs includes a bottom-up approach, focusing on the involvement of stakeholders, coproduction and with that, the inclusion of the end-users (Karpouzoglou et al., 2016; Paparrizos et al., 2023c). This second generation of WCISs requires intensive collaboration between scientists and the group of end users, including capacity building, monitoring and technical support in the design and testing phases of a WCIS tool (Paparrizos et al., 2023c).

4.2.2 Climate Information Provisioning in Kenya

In Kenya, data on climate change is lacking because global data is not downscaled to local levels (Lennard et al., 2018). For instance, there is a shortage of data on the highly variable precipitation in some regions (Herrero et al., 2010). The lack of access to relevant weather forecasts among most farmers in Africa results in a lower capacity to tailor their agriculture to the weather conditions (Marigi, 2017). If provided, WCISs are supplied by the Kenyan government but also by non-governmental, community-based, and international organisations (Muema et al., 2018). Short media messages, internet, newspapers, radio, televisions, bulletins, internet, and trained individuals are some of the ways through which the Kenya Meteorological Department provides WCISs (Muema et al., 2018). Ngigi and Muange (2022) state that mobile phone applications, digital platforms and farmer organisations are of importance in the provision of climate information. In Kenya, only 40% of the participating farmers use information from seasonal WCISs to make agricultural decisions (Muema et al.,2018). Muema et al. (2018) highlight that the primary obstacles for smallholder farmers to use WCISs in agricultural decisions are a lack of trust in and unreliability of WCISs.

4.2.3 Co-production of Weather and Climate Information Services

To make sure the WCIS aligns with the contextual needs, co-producing the WCIS is crucial. Co-production is a bottom-up approach, a process in which end-users participate in the process of developing a product, in this case, a climate information service (Kumar et al., 2021). Co-production focuses on the (co-)implementation with citizens (Brandsen & Honingh, 2018), requiring a transparent and credible process (Nyadzi, 2020). The success of WCISs depends largely on the level of involvement of the farmers (Vedeld et al., 2019). Co-production of WCISs allows for weather forecast knowledge of local people to be part of the creation process (Paparrizos et al., 2024). As a result, scientific and local knowledge can be combined (Figure 3) to produce the best adaptation to climate change while at the same time offering social learning by learning from others (Bremer & Meisch, 2017).

For WCISs to be useable, they must align with the local context, for example, accounting for existing knowledge, stakeholders, the ability to use information and the planning phase (Van der Horst et al., 2022). Participating in the process increases trust in the WCIS (Kumar et al., 2021) by creating a feeling of ownership of the information (Paparrizos et al., 2024). Engaging farmers can enhance the acceptability and reliability of WCISs (Nyadzi et al., 2022), while also improving the capacity to understand and use scientific and local forecasts (Paparrizos et al., 2023b). Additionally, co-production can empower users and mobilise them to deal with climate change issues (Bovaird, 2007) and provide feedback on the service (Kumar et al., 2021). By co-producing a service, the service is more tailored to the farmers' needs.

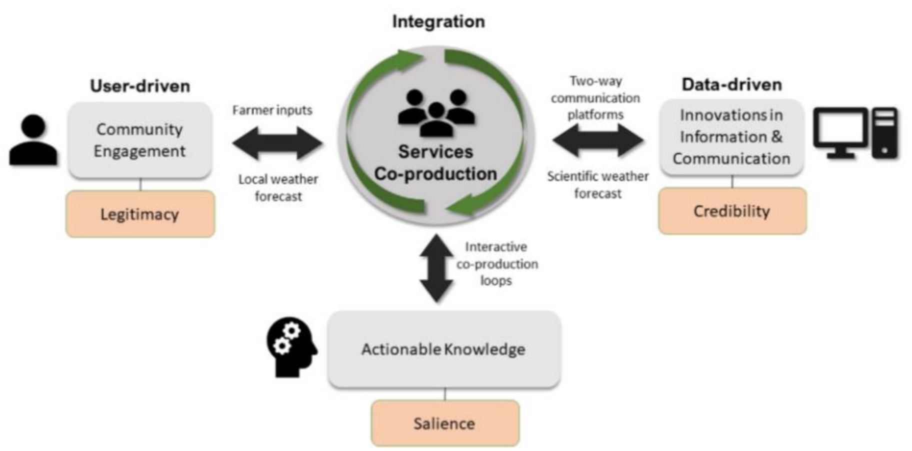

Figure 3 Socio-technical integration of Local weather Forecast and Scientific weather Forecast into a Weather and Climate Information Service through co-production (Paparrizos et al., 2024).

4.2.4 Global Framework for Climate Services

As climate change intensifies, there is a growing need for reliable WCISs. The Global Framework for Climate Services was established to improve climate services and enhance the access to and use of climate services, aiming to improve adaptation to climate change (WMO, 2014). The Global Framework for Climate Services is based on needs such as developing the capacity and collaboration of professionals and communities and improving the quality of the services by conducting research in climate-sensitive sectors, such as agriculture (WMO, 2014).

The Global Framework for Climate Services is built upon five pillars putting cooperation at the heart (Figure 4). The User Interface Platform pillar focuses on structured interaction between producers, users and researchers (WMO, 2014). The Climate Services Information System pillar focuses on the collection and management of climate data to support complex climate-sensitive decision-making. Performing constant observation and monitoring of climate and other data in pillar 3 should ensure that the needs of the end-users can be met. The fourth pillar is built upon activities regarding research, modelling and prediction of climate information to be able to provide information about the impacts of climate change and to make the climate services as cost-effective as possible. It targets the practical implementation of the framework (WMO, 2012). The final pillar Capacity Development focuses on the development of the other four pillars and of basic requirements (WMO, 2014).

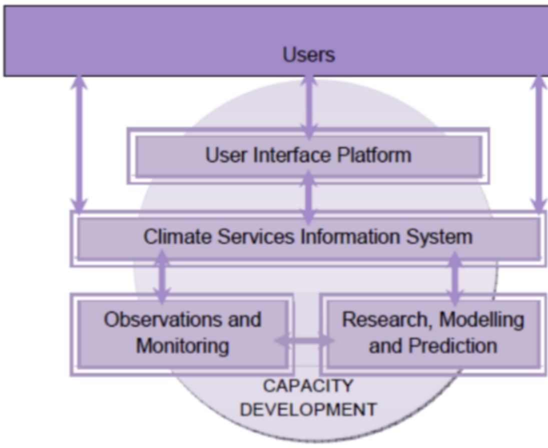

Figure 4 Illustration of the Five Pillars of the Global Framework of Climate Services established to improve climate services and enhance access to and use of Climate Services (WMO, 2014)

4.3 Weather Forecast Knowledge

4.3.1 Local Weather Forecast Knowledge

The term Local Knowledge (LK) is often used in contrast to Scientific Knowledge (SK), with SK referring to 'modern' knowledge and LK to the knowledge systems of a local community (Ajibade & Shokemi, 2003). Alternative terms for LK include traditional knowledge, indigenous knowledge, rural knowledge, and indigenous ways of knowing (Enock, 2013). LK is generally characterised by being local in scale, collectively owned, verbally conveyed, holistic and adaptable (Mistry et al., 2018). LK is becoming more recognised and crucial for preserving indigenous culture and rights as well as for guiding environmental management, but it is still not regularly adopted, partly due to power dynamics between actors (Mistry et al., 2018).

Farmers in the eastern part of Africa largely depend on their Local weather Forecasting Knowledge (LFK) (Radeny et al., 2019). This knowledge is based on their local weather indicators and experiences with observing and forecasting weather conditions (Paparrizos et al., 2023a; Radeny et al., 2019). Local knowledge systems incorporate knowledge about the past, in terms of both disasters and climate, based on experiences and are intergenerationally transferred (Enock, 2013). This traditional weather forecasting is used to inform their agricultural decision-making (Irumva et al., 2021).

Smallholder farmers predict weather based on local ecological indicators, known as LFK indicators (Kumar et al., 2020; Paparrizos et al., 2023a). Meteorological, animal, plant, astrological, human and other indicators are often mentioned as main categories of LFK indicators (Paparrizos et al., 2023a; Radeny et al., 2019; Speranza et al., 2010; Vervoort et al., 2015). Within these primary categories, sub-categories can be identified, such as insect behaviour, birds' behaviour, wind, thunder and stars (Paparrizos et al., 2023a; Radeny et al., 2019; Speranza et al., 2010).

4.3.2 Scientific Weather Forecast Knowledge

Scientific Knowledge (SK) is referred to as modern knowledge based on methods of, for example, observation, data analysis and simulations (Gbangou et al., 2021). Scientific weather Forecast Knowledge (SFK) includes weather forecasts from large-scale models, and satellite and station datasets (Paparrizos et al., 2023a). A scientific forecast is primarily based on the anomalies in the surface temperature of the sea (International Research Institute for Climate and Society, n.d.). These forecasts are then downscaled to the regional level by, for example, the meteorological service of a country (Chagonda et al., 2013). Scientific forecasting is often developed on a larger spatial scale (Nyadzi et al., 2022) and categorised as data-driven as it is derived from weather models. Scientific weather forecasts are often hard to access or do not contain information that is downscaled to the farmers' location (Paparrizos et al., 2023b).

4.3.3 Hybrid Weather Forecast

The reasons for smallholder farmers often combining SFK with LFK include the limited applicability of SFK on the local scale and smallholders' limited understanding and acceptance of SFK (Gbangou et al., 2021; Nyadzi et al., 2022; Paparrizos et al., 2023b; Paparrizos et al., 2024). Merging the SF and LF into a WCIS produces a hybrid weather forecast that could be more accurate and trustworthy while preserving LFK (Paparrizos et al., 2024).

5. Materials and Methodology

5.1 SAFE4ALL project

This study was conducted within the project Safeguarding African Foodsheds and Ecosystems for all Actors across Local, regional and international Levels to manage migration (SAFE4ALL), which is funded by the Horizon Europe Framework Programme (SAFE4ALL Africa, n.d.). The primary aim of SAFE4ALL is to address food security, migration issues and disaster management by supporting the decision-making of local and regional actors in Kenya, Ghana and Zimbabwe (SAFE4ALL Africa, n.d.). A concept used is climate services as an adaptation strategy, intending to develop climate services that meet local needs by involving the end-users in the production process (SAFE4ALL Africa, n.d.).

5.2 The DROP App

The DROP app, a tool used in this study, is created through co-production and is defined as a hydro-climatic information service to meet smallholder farmers' needs for weather and climate information. The app is focused on and tailored to small-scale rainfed agriculture (Sutanto et al., 2025). The DROP app is a hybrid forecast, meaning that it integrates both LFK and SFK and it contains several features to facilitate simple use (Sutanto et al., 2025). Visualisations of the DROP app are shown in Appendix A, as part of the DROP app Manual used in this study. Farmers can share their weather predictions based on observed local indicators, creating a LF for the area (Sutanto et al., 2025). Farmers can view the LF issued by others in the same location as well as the SF based on the Meteoblue forecast from the NOAA Environmental Model System (Sutanto et al., 2025). The SF offers rainfall probability (%) for 1-, 7- and 14-days and rainfall categories ranging from low, to medium, to high and very high (Figure A5). The LF has a 2-day lead time and rainfall categories ranging from low, to medium, to high and very high show the perception of the amount of precipitation (Figure A9) (Sutanto et al., 2025).

5.3 Research Design

To address the sub-research questions (SRQs) and consequently the main research question (MRQ), a variety of research data collection methods was used, as shown in Figure 5. A literature review was used to research LFK indicators in Kenya to inform SRQ1. Farmer interviews and a baseline survey served to identify LFK indicators in Narok North to answer SRQ1. The baseline survey also gathered data to understand the role of LFK and SFK in Narok North (SRQ2). Lastly, training sessions with farmers with the DROP app provided information on the experience of farmers with the app. The training sessions, together with key informant interviews, informed SRQ3 on the potential of the DROP app in Narok North. The key informant interviews were conducted to create a more comprehensive understanding of the community's context and needs. This mixed-method approach offers a more comprehensive understanding compared to using one research method (Almeida, 2018). Data collection took place from October to December 2024. The interviews and questionnaires were conducted in five different wards of Narok North. The training sessions took place in two wards of Narok North.

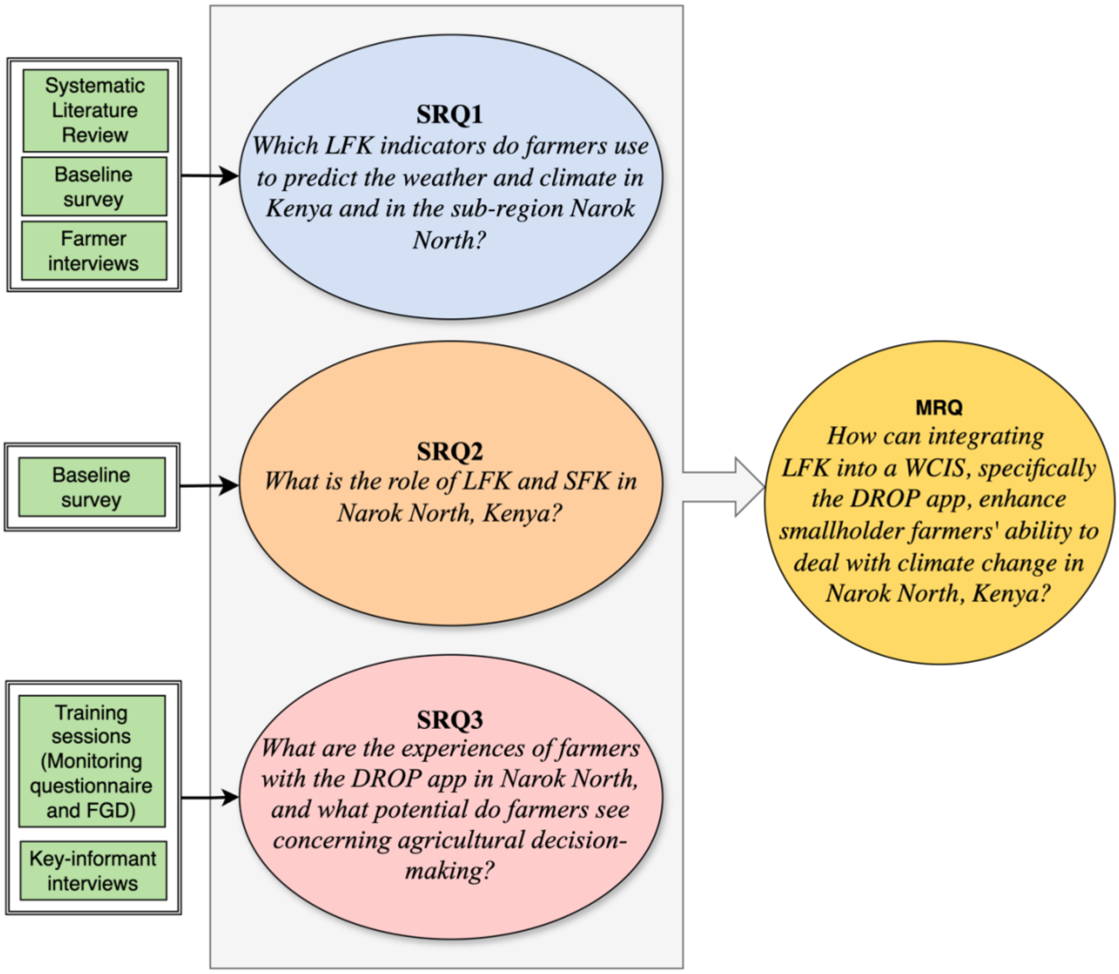

Figure 5 Research Design: Illustrating the Methods applied to each Sub-Research Question

5.4 Data Collection

5.4.1 Systematic Literature Review

A systematic literature review (Efron & Ravid, 2018; Knopf, 2006; Rowley & Slack, 2004) was conducted to create an overview of LFK indicators used by farmers in Kenya. The systematic literature review was carried out adopting the steps described by Kable et al. (2012), described in four phases similar to Paparrizos et al. (2023a).

Searching (steps 1-3 of Kable et al., 2012): The aim was to find articles on local ecological indicators used by farmers in Kenya. A search was conducted using Google Scholar in November 2024 to find relevant literature. Snowball sampling was used to identify other relevant articles by reviewing the reference lists of initially identified articles. The search was restricted to sources available in the English language.

Screening (steps 4-6): No exclusion criteria were used for the publication date, as all indicators were considered valuable. The following search string was used: ("Local Forecast Knowledge" OR "Local weather Forecast Knowledge" OR "Local weather predictions" OR "Indigenous forecasting knowledge", Traditional Forecasting Knowledge") AND ("Kenya" OR "Eastern Africa" OR "Sub-Saharan Africa"). The documentation of the search process is provided in Table B1 in Appendix B.

Screening and critical appraisal (steps 7-12): By reading the abstract, study area, and results, each of the retrieved articles was evaluated for relevance to this study. Articles that did not mention LFK indicators specifically, did not focus on agriculture or did not mention indicators in Kenya were excluded. Duplicate articles from the two databases were removed. The initial search conducted through Google Scholar identified 193 articles. After screening for duplicates and removing articles that were deemed irrelevant to this study, a final selection of 5 articles was included for the literature review. A summary of the selected articles is provided in Table B2 Appendix B.

5.4.2 Baseline Survey in Narok North

The primary aim of the baseline survey was to create an image of the communities' characteristics and provide information on the role of LFK and SFK in Narok North, as well as LFK indicators, rather than specifically understanding the indicators. To achieve this, the questionnaire developed by the SAFE4ALL project was adapted to fit this study (Appendix C). Modifications entailed adding additional LFK indicator categories to distinguish between different types of LFK indicators.

A total of 63 baseline surveys were conducted across the wards in Narok North. Eight baseline surveys were excluded from the analysis due to the total farm size being more than 10 hectares, exceeding the FAO's definition of small-scale agriculture used in this study, which limits itself to farms up to 10 hectares (FAO, 2015). Snowball sampling was used to reach participants with the assistance of an agricultural extension officer from the region. This approach was chosen to ensure access to the wards. In some cases, this led to random sampling as additional respondents were identified during the fieldwork.

The baseline surveys were conducted in person to allow for clarification of questions and so that each participant could fully comprehend the questions. This face-to-face approach was particularly important in ensuring that farmers with limited literacy were included. The surveyor was accompanied by a local resident or agricultural extension officer from the ward. This approach helped to build trust with the participant. Additionally, the local resident assisted with translation when communication in the local language was necessary, ensuring that the questions and the participants' responses were well understood.

5.4.3 Semi-structured Interviews with Smallholder Farmers in Narok North

The primary aim of the semi-structured interview was to identify LFK indicators in Narok North. Individual semi-structured interviews were conducted in person with smallholder farmers throughout five wards in Narok North, as Olpusimoru was inaccessible. Using open-ended questions allowed for flexibility in responses (Bernard, 2006), making it possible for the interviewee to mention what they perceived LFK and LFK indicators to be. The interview guide can be found in Appendix D.

A total of 64 interviews with smallholder farmers were conducted, using a snowball sampling facilitated by agricultural extension officers and local residents. This sampling method was chosen to ensure a diverse range of interviewees. In some instances, interviews were conducted in small groups, facilitating the identification of more indicators. The overlap between interviewees and baseline respondents was minor. The interviews took approximately five to ten minutes to allow for a focus on LFK indicators. This approach was chosen to ensure that participants could provide detailed information on LFK indicators.

5.4.4 DROP App Training Sessions

Training sessions with farmers with the DROP app were done to explore the experiences of farmers with a hybrid forecast and understand its potential in the area. The training sessions were held in November 2024 in Nkareta ward and Olorropil ward of Narok North. These wards were chosen because of their contrasting agroecological zone: Nkareta is part of the lowlands, and Olorropil is part of the highlands. The training group in Nkareta consisted of seven farmers, while the group in Olorropil consisted of five farmers. The number of participants was based on the number of available farmers, and the preferred size of a focus group being between six and ten respondents (Bhattacharjee, 2012). Two separate wards were chosen as training sessions with the DROP app can foster capacity building within the community. Additionally, since the agroecological zones of the two wards differed, comparative insights could be gathered.

The schedule of the main activities during the three training sessions, based on earlier training sessions with the app in other regions in Africa (Lefèvre, 2022; Paparrizos et al., 2023b; Vellis, 2023), are shown in Table 1. The three sessions took approximately one hour and fifteen minutes.

Table 1 Overview of Activities during the three DROP App Training Sessions including the Key Topics of each session

Session	Topic	Main focus of activity
1	Introduction WCIS and DROP app	• Introduction of researcher and SAFE4ALL • Why is climate information important and for what? • Introduction DROP app • Installation of DROP app on smartphones • Explanation of Navigation through the app with DROP app guide (Appendix A)
2 (1 week after session 1)	Check-in	• First impression (group): challenges/preferences • Monitoring (individual): challenges/preferences/potential • Extra demonstration/explanation if necessary
3 (3,5 weeks after session 1)	Implications DROP app	• Monitoring Questionnaire (individual) • Focus Group Discussion

In the first training session, an introduction to the research and the DROP app was provided. In the second training session, the current use of the DROP app, the challenges and preferences were monitored both in a group and individually to keep the participants engaged in the sessions. In the third training session, a monitoring questionnaire was conducted (Appendix E). The questionnaire was based on earlier monitoring questions by Lefèvre (2022), Paparrizos et al. (2023b), Vellis (2023) and took the elements of the Global Framework for Climate Services into account. The monitoring questionnaire focused on understanding the app, how much the app was used, perceived accuracy of the forecasts and how the app had supported the farmers (and the community) in agricultural decision-making by providing weather information. Additionally, the questionnaire focused on what integrating LFK into the app meant to them and what the potential of the app integrating LFK is.

The focus group discussions in training session 3 were conducted after completing the individual questionnaire to avoid a potential bias. Focus group discussions aim to identify the diversity of experiences and preferences (Hennink, 2014), enabling deeper exploration of the farmers' experiences with the DROP app, implications of the DROP app and feedback on the DROP app. These discussions allowed farmers to elaborate on their experiences with the DROP app and have open discussions about its implications and possible improvements. The focus group discussion consisted of six discussion questions (Appendix E). The participants first answered the questions individually by writing their answer on a Post-it, after which all answers were discussed in the group, encouraging each farmer to participate and allowing each participant to share their opinion. The questions focused on what the farmers liked and did not like about the app, what the challenges of the app were, how the app could be improved and how integrating LFK played a role in fostering agricultural decision-making. The audios of the focus group discussions were recorded.

4.5.5 Semi-structured Interviews with Key Informants

To inform SRQ3 on the potential of a hybrid weather forecast in Narok North, semi-structured interviews were conducted with two agricultural extension officers in Narok North and two employees of the meteorological department. The agricultural extension officers and employees of the meteorological department provided a broader perspective on how weather and climate information is communicated and used. The key informant interviews delved into understanding the effect of climate change, agricultural practices, the current use and dissemination of weather and climate information, the perceptions on LFK and SFK, the role of WCISs in the future and the value of integrating LFK into WCISs. With this, a more comprehensive understanding of the potential of a hybrid forecast was assessed for the whole area. The key informant interview guides can be found in Appendix F. The audio of the interviews was recorded, and notes were taken during the interviews.

4.6 Data Analysis

The baseline survey data was analysed using RStudio by calculating means, frequencies and percentages and visualising the outcomes in bar and pie charts. Notes from the farmer interviews and transcripts of the key informant interviews were coded using ATLAS.ti version 25.0.1. This analysis was carried out via open coding, a coding method through which key concepts and ideas are identified (Bhattacharjee, 2012).

The analysis of the transcript and farmers' Post-it notes of training session three was carried out through Atlas.ti. Using a deductive approach, data was analysed using the themes identified in earlier stages of the research and other studies were examined (Caulfield, 2023). The monitoring questionnaire of the training session was analysed in RStudio, focusing on descriptive analysis.

6. Results

6.1 Local Weather Forecast Knowledge in Kenya

6.1.1 Characteristics of Researched Areas in Existing Literature

The existing literature on LFK in Kenya includes studies by Kagunyu et al. (2016), Kipkorir et al. (2012), Paparrizos et al. (2023a), Speranza et al. (2010) and Vervoort et al. (2015). In these studies, some areas are studied more extensively than others, resulting in variation in the level of detail of indicators across the studies. To provide a balanced overview, this study acknowledges these differences and focuses on understanding the key indicators at a national level. The findings were categorised into main categories adopting the classification by Paparrizos et al. (2023a). These categories include animal indicators, meteorological indicators, plant indicators, astrological indicators and other indicators. A more detailed overview of all indicators found is shown in Appendix G.

In Kenya, research on LFK has been conducted in four different counties: Laikipia County, Vihiga County, Isiolo County and Makueni County. Additionally, the Lake Victoria Basin has been a subject of study, covering multiple Counties in Eastern Kenya, including Vihiga County and part of Narok County. Figure 6 illustrates the locations of the areas researched. In all areas, a bimodal rainfall pattern is present. However, the annual rainfall amount varies. In the regions, the percentages of households that are farming households differ. For example, in Isiolo County, 43% of the households are farming households, compared to 79% in Vihiga County and Makueni County (Gef, 2016). In Laikipia, Vihiga, and Makueni County, mixed farming dominates the agricultural sector, while in Isiolo County, livestock farming is dominant (Gef, 2016). Paparrizos et al. (2023a) focus on ecological indicators worldwide, including Kenya.

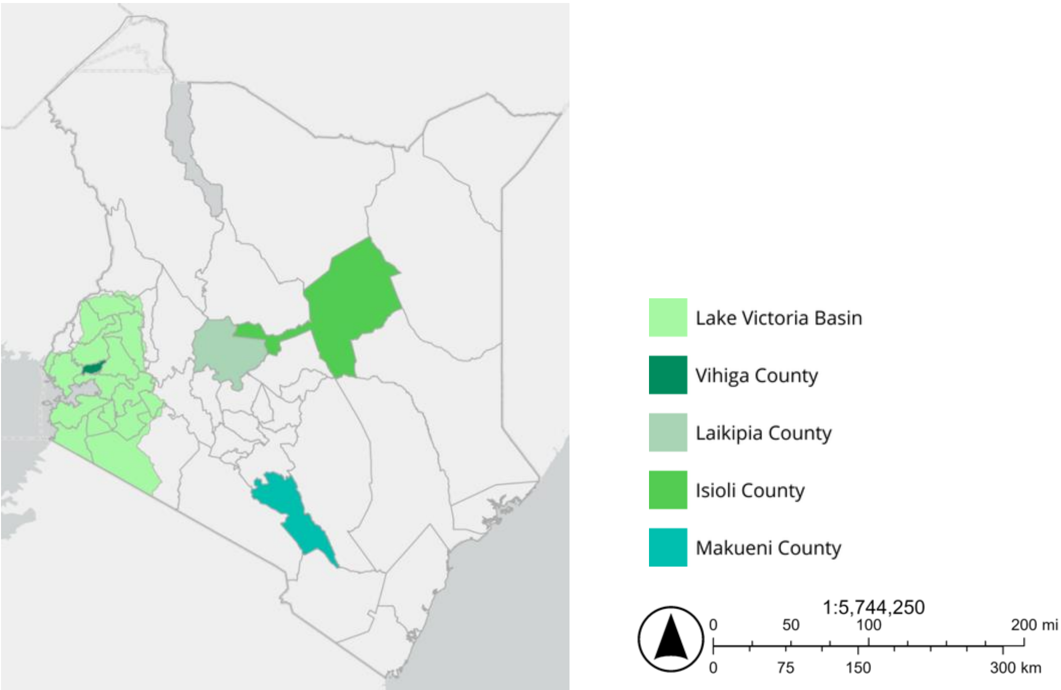

Figure 6 Geographical Representation of Areas in Kenya that have been Researched in the Literature on Local Weather Forecast Knowledge Indicators

6.1.2 Local Weather Forecast Knowledge Indicators in Kenya

In Kenya, meteorological, animal and plant indicators are used as part of farmers' LFK. Nonetheless, there are variations in the use of the other main indicator categories. Astrological indicators are utilised in Lake Victoria Basin, Isiolo County and Makueni County. "Other" indicators are exclusively mentioned in Makueni and Vihiga County. Furthermore, within the subcategories of LFK indicators, bird movements, insect movements, other animal movements and clouds are reported in all researched areas in Kenya. Thunder and lightning, moon, sun and stars, flowering and behaviour of livestock are present in most areas.

Animal Indicators

In Kenya, movements of insects and birds are used as a both predictor of rainfall as well as no rainfall. Ants, flies, and butterflies are examples of insect species to be observed. Except for crickets making noise at night, noted in Makueni County, all insect indicators stress the appearance, disappearance or migration of insects. The appearance of ants has different implications in Kenya: in Makueni County, the appearance of certain ants predicts drought, while in the other regions, it predicts rainfall onset.

Similar to insect indicators, bird indicators used in Kenya focus on appearance, disappearance, movement or migration of birds. Contrary to the insect sounds, bird sounds are widely used as indicators. Furthermore, in several regions, livestock behaviour is suggested as an LFK indicator. For instance, in Makueni County, rainfall is predicted when poultry or cattle 'look weak all the time'. Another example is an increase in the excitement level of cows, mentioned in the Lake Victoria Basin. In Isioli County, 41% percent of the farmers observe the intestines of slaughtered animals to predict the weather. When the intestines are black, it indicates drought; when the intestines are red, it indicates rain onset.

Apart from insects, birds and livestock, other animals are observed, such as croaks of frogs, identified in Laikipia, Vihiga and Makueni County. In Makueni County, the croaking of frogs predicts rainfall, contrary to the other two counties, where it predicts drought. The adoption of this indicator varies across Kenya, with higher usage in Vihiga than in Laikipia and Makueni. Domestic and wild animals are also observed for weather prediction; however, they are only mentioned in Makueni County.

Meteorological indicators

Cloud observations widely serve as an LFK indicator across Kenya and include the formation and movement of clouds. Depending on the area, the appearance of many clouds or few clouds can predict rainfall and drought, respectively. More specifically, nimbus clouds are mentioned in the Lake Victoria Basin and in Makueni County as indicators for rainfall.

In addition to clouds, observation of wind is important in Kenya, except in Isiolo County. The wind direction is important for many farmers in Laikipia County, Vihiga County and the Lake Victoria Basin. In Makueni County, a wind direction indicator constitutes the wind blowing from Mount Kilimanjaro and back before rainfall. Another way to observe the wind is to focus on the strength of the wind, and when the wind blows, as used in Lake Victoria Basin.

While observations of the sun are exclusively mentioned in Makueni County, temperature-based indicators are utilised across Kenya, but not by a high percentage of the farmers. In Laikipia and

Vihiga County, high temperatures suggest rainfall, while in Isiolo County, high temperature suggests drought. Cooler temperatures suggest rainfall for farmers in Laikipia, Vihiga and Makueni County. In the Lake Victoria Basin, temperature is not suggested as an indicator.

Observations of morning dew are present in Vihiga and Makueni County but have different predictive outcomes. Thunder and lightning are LFK indicators used in several areas of Kenya, including Vihiga County, Lake Victoria Basin and Makueni County. However, thunder and lightning are only mentioned by a small percentage of the farmers. An example of lightning as an indicator in Lake Victoria Basin is frequent lightning and horizontal lightning predicting rainfall onset, while horizontal lightning predicts no rainfall.

Astrological Indicators

Astrological indicators are used in Kenya by observing stars, the moon and the sun, but not in all areas. In the Lake Victoria Basin, the stars are mentioned with no specification of how they are observed. In Makueni and Isioli County, indicators of the stars are based upon the presence of stars in the sky or the appearance of the constellation of the seven stars. The constellation of the seven stars is of great importance in Isioli County, suggesting rainfall. The position of the constellation of the seven stars, for example, in the central position or in the east, indicates whether there is drought or non-drought in Makueni County. The moon as an LFK indicator is used in Lake Victoria Basin as well as in Makueni County. However, it is only used by a low percentage in Makueni County. Likewise, a combination of the sun and moon, in which circles appear around one of the two, is only mentioned by a low percentage of farmers in Makueni County.

Plant indicators

At least one plant indicator is mentioned in each of the researched areas in Kenya, focussing on leaves, flowering and blossoming of certain trees and plants. In Laikipia, plants are mentioned in general terms, while farmers in Isiolo and Makueni County mention the falling of leaves as an indicator of no rainfall specifically. In contrast, the falling of leaves suggests the onset of rainfall in Vihiga County. Furthermore, the flowering of trees is particularly important in Isiolo County and Makueni County. In Makueni County, trees that fail to blossom or certain trees that do blossom indicate no rainfall.

Other indicators

Other indicators are not widely suggested, only in Makueni and Vihiga County some indicators that do not fit in one of the above categories are mentioned. Examples are calendar readings, water masses drying up, cooler water temperatures than normal and Mount Kilimanjaro looking dark or clear.

6.2 Local Weather Forecast Knowledge Indicators in Narok North

6.2.1 Characteristics of Baseline Survey Respondents

Table 2 shows the personal and agricultural characteristics of the baseline survey respondents in Narok North. 60% of the respondents were male, and 40% were female. The respondents' average age is 33 years, with 49% of the participants being between the ages of 26 and 40 years. The vast majority of respondents lived in five of Narok North's six wards. The average household size consistsed of 6-7 members. The majority (67%) of the respondents reported having a high literacy level. A large proportion (49%) of the respondents' highest level of education is secondary education. Exploring the agricultural characteristics of the respondents, the average farmland size is 2.89 hectares, with 69% owning less than 4 hectares. Potatoes (58%) and maize (51%) are mainly cultivated in the area. More than 90% of the respondents had less than 20 years of farming experience and for the majority, farming is their only source of income.

Table 2 Personal and Agricultural Characteristics of the Baseline Survey Respondents in Narok North

Personal characteristics

Variables		n	(%)
Gender			
	Female	22	40%
	Male	33	60%
Age			
	18-25	19	35%
	26-40	27	49%
	41-55	6	11%
	55+	3	5%
Location			
	Melili	11	20%
	Narok Town	12	22%
	Nkareta	9	16%
	Olokurto	8	15%
	Olorropil	13	24%
	Olpusimoru	1	2%
	NA	1	2%
Household size			
	0-2 members	4	7%
	2-4 members	10	18%
	4-6 members	21	38%
	6-8 members	13	24%
	8-10 members	5	9%
	10+ members	2	4%
Literacy level			
	None	4	7%
	Beginner level	2	4%
	Medium	12	22%
	High	37	67%
Level of			
	No formal education	7	13%
	Primary Education	14	25%
	Secondary Educatio	27	49%
	Tertiary Education	7	13%

Agricultural characteristics

Variables		n	(%)
Farmland size			
	0-2 hectares	20	36%
	2-4 hectares	18	33%
	4-6 hectares	10	18%
	6-8 hectares	5	9%
	8-10 hectares	2	4%
Main Crops			
	Barley	1	2%
	Beans	11	20%
	Cabbage	5	9%
	Carrots	5	9%
	Maize	28	51%
	Peas	3	5%
	Potatoes	32	58%
	Sweet potatoes	1	2%
	Tomatoes	1	2%
	Wheat	9	16%
Years of farming experience			
	Less than 10 years	25	45%
	10-20 years	26	47%
	20-30 years	0	0%
	More than 30 years	4	7%
Other sources of income than farming			
	Yes	14	25%
	No	41	75%

6.2.2 Local Weather Forecast Indicators in Narok North (Baseline Survey Findings)

According to the baseline survey, the primary LFK indicators used by farmers in Narok North for both males and females are clouds (64%) (Figure 7). This is followed by wind, temperature change, behaviour of livestock, birds' movements and sounds, insect movements and sounds and the moon, sun and stars. Other animals' movements and sounds, flowering, thunder and lightning are mentioned by less than one-fifth of the respondents. More females (20%) mentioned clouds as an LFK indicator, while more males (18%) mentioned the behaviour of livestock as an indicator. Males indicated using the moon, sun and stars more often by 17%.

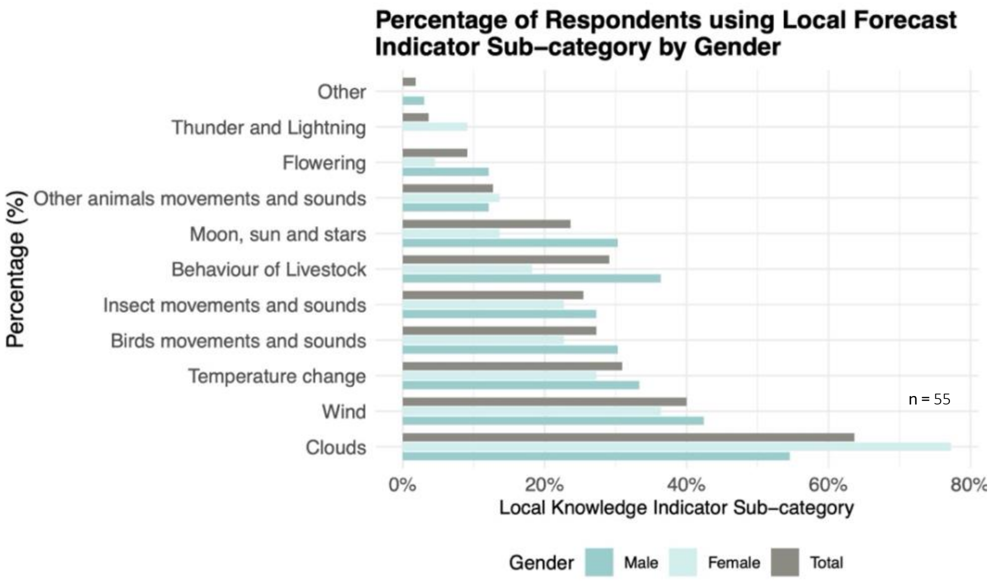

Figure 7 Use of Local Weather Forecast Knowledge Indicators showing the Percentage of Baseline Survey Respondents using each Indicator Sub-Category in Total and broken down by Gender

The visual representation of the data (Figure 8) implies differences in indicator utilisation among different age groups (18-25 years, 26-40 years, 41-55 years, 55+ years). In all age categories, more than two-thirds of the respondents mention clouds, except for the age group of 55+. Farmers in the age category 55+ are the only ones who do not mention insect movements but do mention all other subcategories. Moreover, only the age categories 18-25 and 55+ mention thunder and lightning as indicators. Within the age category 18-25 years, the focus is on temperature change, birds' movements and sounds, wind and clouds. It should be noted that there were only three respondents in the age category 55+.

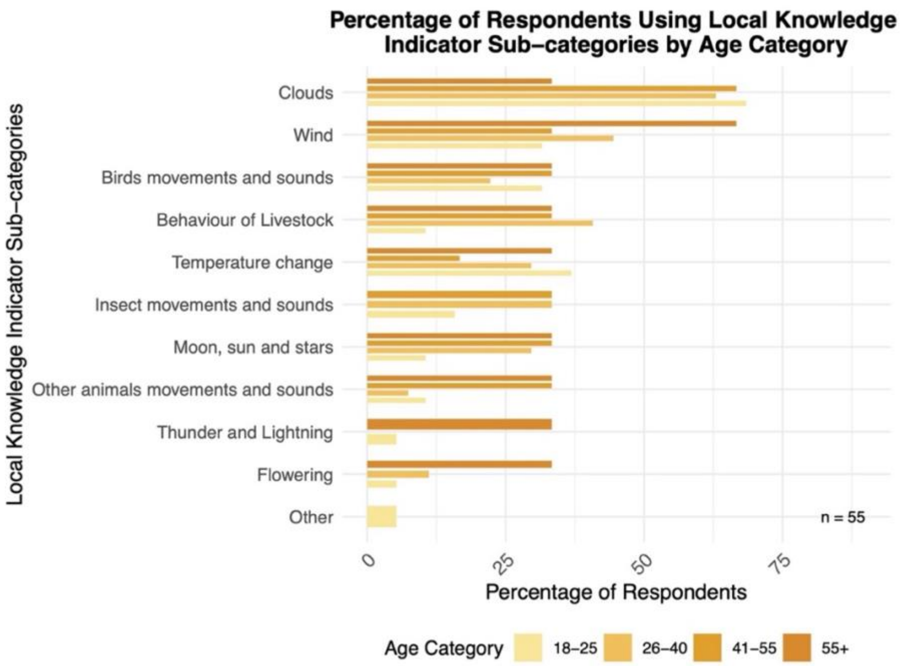

Figure 8 Use of Local Weather Forecast Knowledge Indicators, showing the Percentage of Baseline Survey Respondents using each Indicator Sub-category, broken down into four Age Categories (18-25, 26-40, 41-55, 55+)

The baseline survey's findings were categorised into main categories adopting the classification by Paparrizos et al. (2023a). These categories include animal indicators, meteorological indicators, plant indicators, astrological indicators and other indicators. The findings suggest that meteorological indicators are most widely utilised in Narok North (indicated 76 times). This is followed by animal indicators (indicated 52 times), while plant indicators make up the smallest group. When looking at the geographical location of the respondents, in Olorropil ward, meteorological, astrological and animal indicators are used more than in other wards.

6.2.3 General Characteristics of Semi-Structured interviews with smallholder farmers

The sample of the semi-structured interviews with smallholder farmers consisted of 64 interviews (Table 3). 59% of the respondents were male, and 41% were female. The average age of the respondents was 36 years. The respondents lived in five of Narok North's six wards.

Table 3 Personal Characteristics of Respondents of Semi-Structured Interviews with Smallholder Farmers in Narok North

Personal characteristics

Variables		n	(%)	Variables		n	(%)
Gender				Location			
	Female	26	41%		Melili	8	13%
	Male	38	59%		Narok Town	13	20%
Age					Nkareta	15	23%
	18-25	19	33%		Olokurto	11	17%
	26-40	21	37%		Olorropil	17	27%
	41-55	10	18%		Olpusimoru	0	0%
	55+	7	12%				

6.2.4 Detailed Indicators in Narok North (Interview Findings)

Most indicators mentioned by farmers in Narok North predict rainfall; only a few predicted the onset of rainy seasons. In addition, many farmers could not specify the quantity of rainfall or time frame within which rainfall will occur that the indicator predicts. Additionally, only a small number of indicators suggested no rainfall is expected. Farmers believed that indicators were accurate in their prediction. However, most farmers note that the accuracy of the local weather calendar has declined due to changing historical rainfall patterns induced by climate change.

Meteorological and animal indicators dominated in Narok North and include the widest variety of indicators. Furthermore, insect movements and sounds, bird movements and sounds, livestock behaviour, clouds, and wind make up 68% of the mentioned indicators. The wind as an indicator appeared to be less important than insect movements and sounds. Plant indicators did not seem to be of importance to farmers. A description of the indicators found is shown in Table 4 and Table 5.

Animal indicators

Animal indicators were based upon behaviour, movements and sounds. Insect indicators involved the appearance, migration or direction of movements of different insects. Farmers mentioned four insect species: safari ants, butterflies, flies and white termites. Among these, the appearance and direction of movement of safari ants were most frequently reported. Similar to the insect-based indicators, bird-based indicators largely contained movement, migration or appearance of birds, with only one indicator focusing on bird sounds. Farmers were often unable to recall or name the bird species and instead refer to general characteristics such as small or large birds or bird movements in general. Other indicators were based on the behaviour of livestock, in particular cows and sheep. The loud croaking of frogs and the playful behaviour of domestic animals were also noted as signs of rainfall by some farmers.

Meteorological indicators

Farmers used various ways to observe clouds to predict rainfall, focusing on either the appearance of a certain type of cloud or their movement patterns. For example, some farmers associated dark clouds, often a characteristic of nimbus clouds, with rainfall, while others suggested that light clouds indicate rainfall. Wind was another key indicator. Rainfall will occur when the wind moves from east to west or south to north, while the opposite directions suggested no rainfall. One farmer noted that rainfall occurs when the wind starts moving in a circular pattern.

Other meteorological indicators involved sunlight and temperature. The presence of a strong sun during the day or morning implies rainfall. High temperatures at night as well as unusually high temperatures during the day suggested rain. Additionally, according to some, the appearance of dew or changes in the appearance of morning dew signified the onset of the short or long rainfall season. A group of farmers mentioned observing the presence of mist in the valleys as a rainfall indicator.

Astrological indicators

Astrological indicators included observing the stars, the moon or a combination of both. The appearance of stars in general, or more specifically, the appearance of the constellation of the seven stars, was believed to imply rainfall. Some suggested that when the constellation of the seven stars appears close to the moon, rainfall occurs. However, one farmer noted that this alignment no longer occurs. Another farmer suggested that only elders can interpret stars as an indicator.

The appearance of the full moon is referenced by one-fifth as an indicator of the onset of the short or long rainfall season. In contrast, less common indicators were the direction of the movement of the moon or the moon’s appearance in the west at 7 PM.

Plant indicators and ‘Other’ indicators

Plant indicators only accounted for 2% of all indicators and include changes in the colour of grass, the falling of leaves and the flowering of plants and trees. ‘Other’ indicators, which do not fit into the specified categories, included the echoing of sounds such as voices.

Table 4 Description of Local Weather Forecast Indicators mentioned in Semi-Structured Interviews with Smallholder Farmers in Narok North, organized by Main and Sub-categories, showing the forecast of each indicator and the percentage of Respondents using the indicator (Continuous on Next Page)

Indicator main category	Indicator (Sub-Category)	Forecast of indicator		n	(%)
ANIMAL (45%)	**Insect movements and sounds**			**60**	**22%**
	Appearance and direction of movement of safari ants	rainfall	rain within 1-2 days	44	16%
	Appearance of butterflies	rainfall		6	2%
	Migration of butterflies	rainfall		4	1%
	Direction of movement of butterflies	rainfall		1	0%
	Direction of movement of flies	rainfall		1	0%
	Construction of small mountains by white termites	rainfall		4	1%
	Birds movements and sounds			**27**	**10%**
	Migration of weaver birds in groups	rainfall		8	3%
	Migration of pulea birds	rainfall		5	2%
	Appearance of small birds	rainfall		4	1%
	Appearance of large birds	rainfall		4	1%
	Appearance of salambala birds	rainfall		4	1%
	Movement of birds	rainfall		1	0%
	Sounds of certain type of bird	rainfall		1	0%
	Livestock (behaviour)			**27**	**10%**
	Reduction excitement level of cows	rainfall		8	3%
	Direction of movement of cows (e.g. cows move towards the river)	rainfall		5	2%
	Increase of running of cows and decrease of appetite of cows	rainfall		4	1%
	Cows have a sense of smell	rainfall		4	1%
	Increase of running and mowing of cows	rainfall		1	0%
	Sheep begin shaving themselves	rainfall		4	1%
	Intestines of sheep are red	rainfall		1	0%
	Other animals movements and sounds			**10**	**4%**
	Load croaking of frogs	rainfall	Long rain seasonal onset	6	2%
	Increase of playing of domestic animals	rainfall		4	1%
METEOROLOGICAL (42%)	**Clouds**			**45**	**16%**
	Active movement of the clouds	rainfall		29	11%
	Appearance of thick dark clouds	rainfall		8	3%
	Appearance of nimbus clouds	rainfall		8	3%
	Appearance of light clouds	rainfall		5	2%
	Wind			**28**	10%
	Direction of wind from east to west	rainfall		12	4%
	Direction of wind from west to east	no rainfall		1	0%
	Direction of wind from south to north	rainfall		5	2%
	Direction of wind from north to south	no rainfall		5	2%
	Direction of wind	rainfall		4	1%
	Movement of the wind in a circular pattern	rainfall	Long rain seasonal onset	1	0%
	Sun			**19**	**7%**
	Appearance of an unusual bright sun	rainfall		13	5%
	Appearance of bright and burning sun	rainfall	(a large amount of rain)	4	1%
	Appearance of hot sun around 10 or 10:30 AM	rainfall		1	0%
	Appearance of rainbow around the sun in the morning	rainfall		1	0%
	Dew			**9**	**3%**
	Appearance of dew	rainfall	onset of rainfall season	5	2%
	Change in the amount of morning dew present	rainfall	long rain seasonal	4	1%
	Temperature			**8**	**3%**
	High temerature compared to normal days	rainfall		8	3%
	Increase of temperature at night	rainfall		4	1%
	Mist			**4**	**1%**
	Appearance of mist in the valleys	rainfall		4	1%
	Combination of meteorological indicators			**1**	**0%**
	Appearance of a lot of clouds and low temperature	no rainfall	the current ongoing rainfall will stop	1	0%

Table 5 Description of Local Weather Forecast Indicators mentioned in Semi-Structured Interviews with Smallholder Farmers in Narok North, organized by Main and Sub-categories, showing the Forecast of each Indicator and the Percentage of Respondents using the Indicator (Continued)

Indicator main category	Indicator (Sub-Category)	Forecast of indicator		n	(%)
ASTROLOGICAL (8%)	**Moon**			**12**	**4%**
	Appearance of the full moon	rainfall	long rain seasonal	11	4%
	Appearance of the moon in the west at 7PM	rainfall		1	0%
	Direction of movement of moon	rainfall	rain within 15-days	1	0%
	Stars			**8**	**3%**
	Appearance of stars at night	rainfall		4	1%
	Appearance of the constellation of the seven stars	rainfall		4	1%
	Combination of astrological indicators			**1**	**0%**
	Appearance of the constellation of the seven stars close to the moon	rainfall		1	0%
PLANT (4%)	Change of color of grass	rainfall		6	2%
	Falling of leaves of plants	rainfall		2	1%
	Flowering of plants	rainfall		1	0%
	Flowering of trees	rainfall		1	0%
OTHER (2%)	Echoing of sounds (e.g. voices)	rainfall		5	2%

6.4 The role of Local and Scientific Weather Forecasts in Narok North

Out of 55 baseline survey respondents, 42 indicated that they used weather information for agricultural decision-making. It should be noted that 13 respondents who indicated not to use weather information later indicated to rely on sources of weather information. This is inconsistent with their answer on whether they use weather information. 90% of the respondents followed rainfall information, 31% followed temperature information, and 16% used wind information to inform their agricultural decision-making. None of the farmers suggested following another type of weather information. Most farmers indicated using LFK as a source of weather information. 75% of the participants reported using LFK in the form of ecological indicators, and 46% expressed using the local weather calendar (Figure 9). SFK was less commonly used but was mostly accessed through weather websites (32%), such as Google. Farmers often combined multiple weather information sources to support their agricultural decision-making.

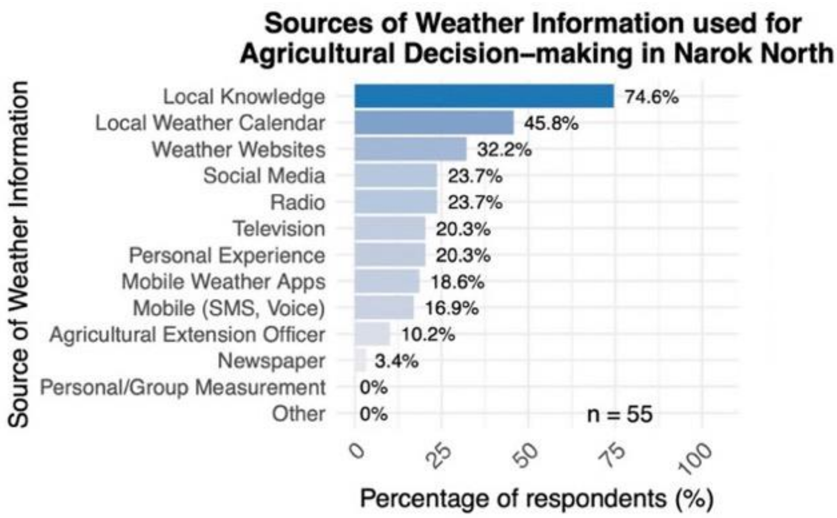

Figure 9 Percentage of Baseline Survey Respondents using a Source of Weather Information for Agricultural Decision-making in Narok North

While many baseline survey participants indicated using ecological indicators and the local weather calendar, the percentage of farmers that prefer it as a source of weather information is lower. 29% preferred using ecological indicators, and 18% preferred relying on the local weather calendar. This was followed by news or weather websites, mobile weather applications, mobile, radio and social media, which were all preferred by between 7% and 11% of the respondents. Personal experience, agricultural extension officers and television are the least preferred sources of weather information.

Participants slightly preferred using a mix of LFK and SFK (38.2%) (Figure 10), whereas 35% favoured LFK and 27% favoured SFK. Although there was a difference in the preference among the different wards, no conclusions could be drawn due to the limited number of participants per ward.

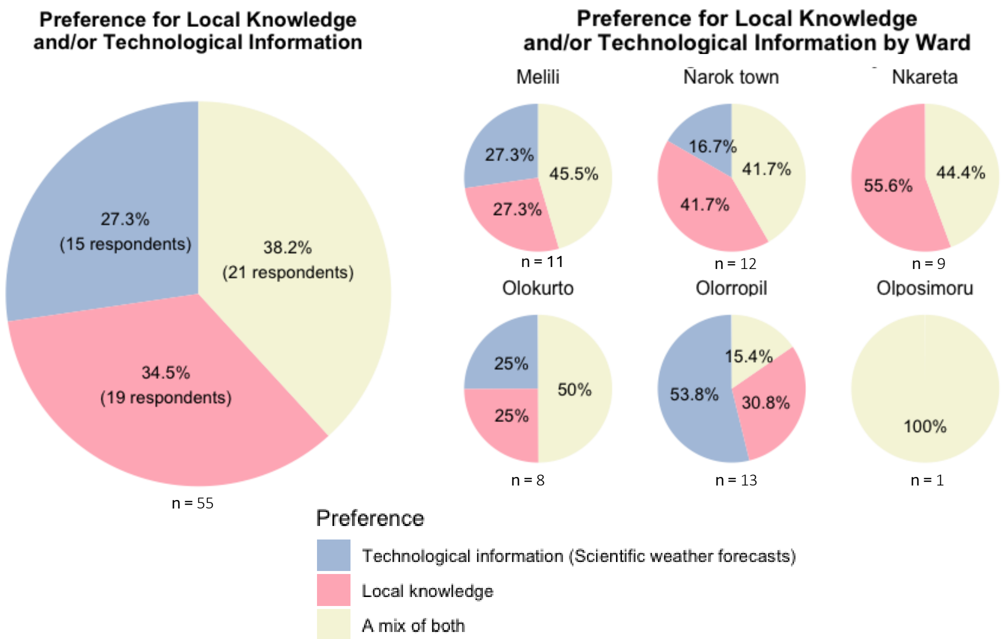

Figure 10 Percentage of Baseline Survey Respondents preferring using Local Knowledge, Scientific Knowledge or a Mix of Both, illustrated in Total and Brok Down into the Six Wards of Narok North

95% of the farmers expressed requiring more weather information than currently available to them. 71% of the respondents expressed facing challenges in accessing weather information. Examples of mentioned challenges are inaccurate weather prediction, lack of internet and lack of communication. According to two agricultural extension officers of Narok North, additional challenges are lack of (smart)phones, lack of understanding of SF, lack of trust in SF and illiteracy. The Kenya Meteorological Department adds that there is a language barrier, a lack of resources to spread SFs and a lack of knowledge about the existence of SF.

While 57% of the baseline survey respondents rate the quality of the weather information that is currently available to them as good or very good, 27% rate it as acceptable and 16% rate it as poor or very poor. The baseline survey respondents indicate a need for information on the amount of rainfall (75%), timing of rainfall (66%) and temperature (58%). Less than 50% mention requiring more information on humidity.

6.5 DROP App Training Sessions

6.5.1 Use of the DROP App

Following the first training session, farmers expressed having a clear understanding of the DROP app's functionality. While none of the farmers reported having a lot of difficulty navigating through the app, a few found it moderately challenging. They did not specify the initial challenges. Farmers expressed their satisfaction with the app's visual presentation, as discussed in the focus group discussions. All farmers, except one, used the DROP app daily by checking the rainfall forecast. Three farmers used the app multiple times a day. Farmers indicated that they shared their LF four to five times a week on average, with some only sharing their observations every two or three days. Their preferences in the provided forecasts varied. In the monitoring questionnaire, ten farmers primarily used SF, while two preferred using a combination of the local and scientific forecast. In the scientific forecast options, the 7- and 14-day forecasts were most preferred. During the focus group discussions, many farmers highlighted the accuracy of the forecasts, and one emphasised the 14-day forecast's relevance for agricultural planning. The accuracy of the LF was rated between "acceptable" to "very good", slightly leaning towards "very good". The SF accuracy was similarly rated between "acceptable" to "very good". No barriers to understanding the forecast or app were found.

6.5.2 The Challenges and Potential of the DROP App

Supporting agricultural decision-making

The availability of rainfall information through the DROP app positively influenced agricultural decision-making among the farmers. In the monitoring questionnaire, farmers highlighted the app's provisioning of substantial new information, enabling the planning of agricultural activities due to forecast accuracy. Farmers indicated that this new weather information was helpful for various agricultural activities, including land preparation, planting, applying fertilisers, applying pest control, weeding, harvesting and the choice of crop, all of which received an average Likert scale rating above 4 ("helpful") out of 5 ("Extremely helful"). Planting and harvesting were rated slightly higher than the other agricultural activities, thus the DROP app was most helpful for supporting decision-making in these agricultural activities. Focus group discussions further emphasised the app's usefulness in determining the timing of agricultural activities such as land preparation, planting, chemical application and harvesting. Farmers also noted its role in determining appropriate quantities of chemicals and the selection of seeds and crops. Many farmers stated: "*Information is power*". The findings suggest that the DROP app supports agricultural decision-making by providing useful weather information.

Integrating local knowledge

According to the farmers that took part in the training sessions and the key informants, integrating local knowledge has several implications. An employee of the Kenya Meteorological Department stated: "*They believe so much in their indigenous knowledge; they have their own coping mechanisms. It is location specific; we need to customise and look at the local context*.". Similarly, according to the majority of the farmers that participated in the training sessions, integrating LF makes the app significantly relevant to their specific agricultural conditions, although three indicated moderate or little improvement. Integrating LF encouraged nearly all farmers to use the app, as it improved the accuracy of the forecast. When asked whether the combination of the LF and SF improves the accuracy of the forecast, five farmers indicated "very significantly", three indicated "significantly", and three indicated "moderately". Nevertheless, some farmers expressed scepticism, with two mentioning that the LF was inaccurate and one suggesting that the LF was unnecessary in the focus group discussion. The agricultural extension officers stated combining LF and SF could mutually enhance accuracy since "*LF and SF go hand in hand*".

Farmers agreed that the element of LFK in the DROP app could encourage others to use the app. Focus group discussions highlighted that similarities between LF and SF could make the forecast comprehensible. One farmer indicated that it is more encouraging to the user, and it is possible to "*share the knowledge to the entire society*" by integrating the LF. Kenya Meteorological Department representatives noted that because LF is perceived as accurate, the acknowledgement of LFK can increase the understanding and acceptance of SF. Moreover, farmers mention that including LF can enhance the credibility of SFK by allowing for the comparison of both forecasts within the app, demonstrating, for example, that SFK is more accurate than LFK, as one farmer noted. On a Likert scale (range: 1-5), trust in LF (3.9) was lower than in the SF (4.8). Notably, the trust in the combination of the forecasts was rated 5 by all farmers, surpassing each forecast independently. Meteorological Department representatives emphasise that integrating LF fosters a sense of ownership among farmers: "*The richness of the LFK is not in the accuracy but in the acceptability of the scientific forecast.*"

Challenges and potential

Farmers and key informants suggested additional training sessions to enhance the dissemination of the forecasts and the DROP app. Many farmers shared forecasts with others and expressed willingness to recommend the app. The primary challenge of the app was limited internet connectivity, as many farms were located in remote areas where service access was unavailable or expensive. The inability to view forecasts offline complicated usage. Additional challenges were illiteracy and lack of smartphones among farmers.

According to the farmers, the DROP app could significantly enhance climate resilience on their farms. Key benefits identified include preparation for extreme rainfall and drought and increased awareness of rainfall variability. Focus group discussions emphasised that determining the timing of agricultural activities and planting seasons is important to be able to address climate change. Improved on-farm decision-making could help minimise economic losses while maximising agricultural profits, according to the farmers. Agricultural extension officers highlighted that the app’s forecasts could mitigate the unpredictability of rainfall patterns caused by climate change. However, without additional information, it cannot yet account for changing conditions in Narok North, such as increased temperature, land degradation, deforestation, changing rainfall patterns and changing agricultural seasons alone. Nevertheless, accurate and localised forecasts could significantly enhance agricultural productivity.

Farmers suggested offline functionality as a crucial improvement to the app. Forecasts should remain accessible without internet access, even without updates. Additionally, several farmers suggested including information on soil type and moisture, temperature, planting and harvesting schedules, and agricultural inputs. One farmer proposed adding a daily rainfall forecast to help plan daily activities. The Kenya Meteorological Department highlighted the importance of providing farmers with technological knowledge to adapt their practices to changing climate conditions and hazards.

7. Discussion

7.1 Local Weather Forecast Indicators: Reliability and Regional Variability

Although some studies suggest that LFK is becoming less reliable and inaccurate due to climate change (Ebhuoma & Simatele, 2017; Kalanda-Joshua et al., 2011; Okonya & Kroschel, 2013; Ziervogel & Opere, 2010), farmers in Narok North do not share this perception. The majority believes that predictions based on LFK indicators remain reliable, aligning with findings from Gbangou et al. (2021), who reported that most farmers across five communities in Ghana considered LFK indicators as valid. Gbangou et al. (2021) found that the skill of LFK can compete with SF, especially when indicators are combined. This could be why indicators are still widely used among smallholder farmers. Additionally, a decrease in the accuracy of the local weather calendar was observed in Narok North. This can be attributed to changing weather patterns in the region, as Koei (2013) and Shongwe et al. (2011) observed increasing irregularity and variability in the annual rainfall patterns in most of Kenya in the last 50 years.

More LFK indicators in Kenya were defined for short term predictions, predictions for the event occurring within a few days, than seasonal predictions. This finding is mirrored by Gbangou et al. (2021), who observed that short term predictions were nearly twice as common as seasonal predictions in the Ada East District in Ghana. In this study, the difference appears even more pronounced.

It was found that one indicator can have different predictive outcomes for different farmers, meaning it might signal rainfall to one farmer while indicating no rainfall to the other, aligning with Gbangou et al. (2021). The findings further suggest that rainfall is the most commonly predicted outcome of the LFK indicators, which is consistent with findings in Ghana (Gbangou et al., 2021).

The findings of the literature review suggest that some indicators that are used in the Lake Victoria Basin are not used in Vihiga County even though it is part of the Lake Victoria Basin and vice versa. Furthermore, within Kenyan Counties, meteorological and animal indicators dominate, but regional variations exist. These findings show that indicators can be very location-specific, which is consistent with the findings of Paparrizos et al. (2023a) and Ebhuoma & Simatele (2016). According to Eakin (1999) and Pareek & Trivedi (2011), this is because locals have a detailed understanding of their environments.

The dominance of meteorological and animal-based indicators in Narok North is consistent with broader African patterns (Paparrizos et al., 2023a). A lack of human-based indicators in Narok North is consistent with findings from other parts of Eastern Africa (Radeny et al., 2019) and Sub-Saharan Africa (Paparrizos et al., 2023a). However, unlike in other African regions (Paparrizos et al., 2023a), plant indicators are notably absent in the current study. The low usage of plant indicators in Narok North may stem from low vegetation cover. Land degradation may exacerbate the low frequency. Agricultural extension officers and farmers from Narok North reported ongoing deforestation. This reasoning aligns with Radeny et al. (2019), noting that extinction of plants, desertification, and vegetation loss pose threats to LFK.

Cloud observations emerged as a widely used indicator in Narok North and Kenya, although skill analysis of clouds in Ghana suggests that the skill of clouds is lower than other indicators (Gbangou et al., 2021). It could be that clouds are easily observable for everyone and, therefore, widely used. Additionally, it may be possible that this indicator is used in combination with other indicators, increasing the accuracy of the prediction, as found by Gbangou et al. (2021). Another notable finding is that women tend to observe clouds more than men. While this may be related to daily routines, responsibilities, accessibility or cultural factors, the underlying reason remains unclear. No literature was found to either complement or challenge this finding, although Enock (2013) does highlight the necessity of recognising that some components of local knowledge are highly gender sensitive. Furthermore, as there are indications that the use of weather information is dependent on gender (Ngigi et al., 2017; Ngigi & Muange, 2022), there is a need to investigate and produce gender-sensitive WCISs (Ngigi & Muange, 2022).

In Narok North, farmers observed wind as the direction in which it blows. In other regions in Kenya, the strength of the wind is also an indicator of rainfall. Thunder and lightning as indicators are not mentioned by many farmers in Narok North in the baseline survey and no examples of this indicator are mentioned in the interviews. Indicators based on thunder and lightning are not widely used in any of the regions in Kenya or across the globe (Paparrizos et al., 2023a).

Livestock behaviour is used by 8% of the farmers in Narok North, accounting for one of the largest subcategories. This can be attributed to most farmers practicing multi-farming and herding livestock. Livestock-based indicators are also used in Lake Victoria Basin, Isioli County, and in Makueni County, where the studies did not solely focus on crop farming as in Laikipia and Vihiga County. Notably, Paparrizos et al. (2023a) do not mention livestock behaviour as a separate indicator category, making it unclear whether it is used globally. Furthermore, the current study found that men reported livestock-based indicators more frequently than women. This discrepancy may be explained by cultural factors, as in the Maasai community, the dominant community in Narok North, men are traditionally responsible for herding livestock.

7.2 Dependence on Local Weather Forecast Knowledge

Since agriculture in Narok North, Kenya, is predominantly rain-fed, access to reliable weather information is crucial for agricultural decision-making. While some farmers initially reported not using weather information, this response appeared inconsistent as they later identified various sources of weather information. This could suggest that these farmers, in practice, do use weather information and do not associate the term “weather information” with rainfall forecasting. This possible misunderstanding highlights the need for a clearer definition of weather information when assessing farmers’ use of weather information.

The findings revealed a crucial reliance on LFK for weather prediction among smallholder farmers in Narok North. The baseline survey data identified that LFK plays a crucial role in agricultural decision-making, which is reinforced by qualitative interviews, where every interviewee mentioned using at least one LFK indicator.

While LFK is the primary source of weather information, some farmers acknowledged using SFK. Several farmers suggested that the lower use of SFK could be a result of a lack of location-specific SF forecasts, resulting in inaccurate predictions. A possible explanation for the poor accuracy of SF in the region is a scarcity of weather stations in Narok County, as mentioned by a key informant of the Kenya Meteorological Department. The forecasts provided are on County or sub-County levels. Similar findings were reported in Western Uganda (Nkuba et al., 2022) and by Ebhuoma and Simatele (2017), where inaccurate SF reinforced reliance on LF.

Beyond concerns of accuracy, Radeny et al. (2019) mention a lack of access to and understanding of SFK as leading to reliance on LFK in several parts of Eastern Africa. Limited access to SFK in Narok North may result from infrastructural and socioeconomic barriers. Remoteness of agricultural land, lack of phones or internet, and illiteracy can hinder the distribution and understanding of SFK, further reinforcing dependence on LFK.

7.3 Implications of the DROP App Integrating Local Knowledge

First, the study revealed that acknowledging LFK can enhance understanding and acceptance of SFK. It offers social learning by learning from others (Bremer & Meisch, 2017), as mentioned by a farmer, and it creates the possibility to share the knowledge to society. This increased understanding as a result of integrating LFK is agreed upon by Paparrizos et al. (2023b). However, Paparrizos et al. (2023b) also state it can increase understanding of LFK, which is not explicitly suggested by the farmers in Narok North.

Farmers and key informants identified language as a key barrier to using or understanding the DROP app. Farmers suggested producing the DROP app in the dominant regional language to improve comprehensibility and, therefore, the uptake of the WCIS. This is similar to Nkuba et al. (2022) suggesting that receiving SFs in local languages improves the accessibility of WCISs for farmers, particularly for farmers without formal education.

Second, most farmers and key informants believed combining LFK and SFK can increase the accuracy of rainfall predictions, which is supported by Irumva et al. (2021), Ochieng et al. (2021), Speranza et al. (2010) and Plotz et al. (2017). Irumva et al. (2021) and Gbangou et al. (2021) suggest that accuracy increases because LF and SF both have capabilities and limitations. Each forecast system can benefit from the other to enhance the skill (Gbangou et al., 2021), reflecting the farmers' perspective that the app makes it easier to compare forecasts. Ziervogel and Opere (2010) reason that as LFK is more context-specific, its local features can modify the large-scale meteorological systems that SF are based upon. However, it is noted that combining both systems requires good judgement of the benefits and limitations of each system (Ziervogel & Opere, 2010).

Finally, integrating LFK created a sense of ownership, credibility and trust in the DROP app. Some farmers in Narok North state feeling a "sense of ownership" of the forecast due to sharing their observations. This sense of ownership is also mentioned by Paparrizos et al. (2024), who state that by feeling entitled to information, farmers recognise their inputs are valuable. This improves the legitimacy, ownership and uptake of WCISs among farmers. Accounting for currently used knowledge can potentially increase the uptake as it matches their local context (Van der Horst et al., 2022). Farmers and key informants indicated that by sharing their observations, they became actively involved in the creation of the WCIS, fostering trust, a point supported by Kumar et al. (2021) and Nyadzi et al. (2022)

7.4 The Role of the DROP App in Supporting Small-scale Agriculture

This study highlighted that the DROP app supports agricultural decision-making for smallholder farmers in Narok North. Research in Ghana suggests that information through a weather app can support decision-making in activities such as sowing and planting dates, weeding dates, fertiliser application, herbicide application and harvest date (Paparrizos et al., 2024), aligning with the agricultural activities mentioned in Narok North.

Farmers suggested it could be economically beneficial to receive better weather information by planning agricultural activities. This finding is also present in Ghana and Bangladesh, where investment costs for farming inputs dropped after adjusting agricultural activities based on the WCISs forecasts (Paparrizos et al., 2024). Ayal et al. (2015) state that the reliability and precision of a source determines the credibility and acceptance by end-users to use the forecast as a base for their agricultural decision-making. Thus, it could be suggested that the DROP app can support agricultural decisions as long as the forecast is perceived as accurate and reliable. However, it should be noted that the DROP app does not combat other challenges, such as crop loss due to a lack of market or market access.

Farmers were generally positive about the SF of the DROP app, possibly because it fulfils their needs for additional weather information. This need for more detailed weather information on amounts, intensity, duration and timing of rainfall aligns with needs in other countries in Eastern Africa (Radeny et al., 2019). In the baseline survey, farmers indicated requiring more weather information on the timing and the amount of rainfall, which the DROP app provided.

The findings of the training sessions imply that farmers perceive the DROP app as a tool that can assist in addressing climate change. Farmers argued that an accurate forecast can provide crucial information to mitigate climate hazards. Bovaird (2007) argues that co-production can empower users to deal with climate change issues. However, the relationship between co-production and the capacity to deal with climate change may not be as direct. Instead, co-production, in this case through integratingf LFK into WCISs, appears to enhance the accuracy, understandability and credibility of the weather forecast. Farmers indicated that this increases their trust in the DROP app as a reliable source of weather information. Consequently, this can play an essential role in empowering farmers to make informed decisions and, with that, strengthen their capacity to adapt to climate change.

8. Limitations and Recommendations

A limited number of baseline surveys and interviews were conducted due to difficulty in accessibility of locations in combination with time constraints, limiting the generalisability of the results. Due to the small sample size per ward, generalisations of differences and similarities on a local level was not possible. Additionally, only three of the baseline survey participants were in the age category of 55+, which is not representative of the demographics of the area's population. It could be interesting to document more indicators from this age category, providing insight into how the indicators differ from the younger generations. More focus can be on how the LFK indicators are used and could explore how intergenerational transfer of LFK indicators takes place as they are often intergenerationally transferred.

As there might be a correlation between demographic factors and preferences for LFK, LFK indicators and SFK, statistical testing on a larger sample could be performed in future research. Contextual factors such as local climate conditions or culture may also play a role. Therefore, future research could explore to what extent contextual factors can influence the role of LFK, LFK indicators and SFK for farmers. Furthermore, as farmers struggled to specify timeframes for their LFK indicator predictions in the interviews, explicit focus on LFK indicators or the timeframes could help get this information. Therefore, further studies could explore the LFK indicators of this region in greater detail.

Since farmers in Narok North still perceived LFK indicators as reliable, further research could investigate the reliability of LFK indicators in Narok North. For example, it could be explored whether indicators are used in combination with each other, potentially increasing the skill of using LFK indicators. Moreover, further research could compare the skill of LFK indicator and SFK in the region or the hybrid forecast. Investigating and comparing the skill of the forecasts could reveal which forecast or whether a combination of forecasts is most reliable for farmers.

Capacity building should be further introduced in the region to help farmers integrate both LFK and SFK to increase their access to and understanding of the best weather information available. Training sessions can enhance the uptake of the DROP app by increasing farmers' ability to use the app effectively. As a larger number of farmers is needed to create the best LF in the DROP app, it should be widely used among the community. Therefore, more training sessions in the area and in other areas are necessary. Continuous monitoring over a longer period is required to evaluate the DROP app and to ensure ongoing improvement.

As language is one of the main barriers to understanding the DROP app, it is suggested to produce the app in the local language. To deal with illiteracy, the app could include visualisations, for example, by using icons to depict weather indicators. Providing offline access to the forecasts would support farmers who have limited internet access. Furthermore, to reach the full potential of the DROP app, investments in infrastructure such as internet networks are necessary to make the DROP app accessible in remote regions.

9. Conclusion

The aim of this study was twofold: documenting the Local weather Forecast Knowledge indicators used by smallholder farmers in Kenya and Narok North, and exploring the potential of a WCIS, specifically the DROP app, to enhance smallholder farmers' resilience to climate change in Narok North.

Results showed local weather forecasting knowledge is crucial in Kenya and Narok North, with meteorological and animal indicators as dominant ecological indicators used by farmers. In Kenya, movements of birds, insects and other animals, together with movements of clouds and wind direction, are key predictors of rainfall, rainfall seasons and drought. While thunder, lightning, and plants are also observed for weather prediction in Kenya, astrological indicators are less common. In Narok North, most indicators predicted rainfall, and some signalled the onset of rainfall seasons or no rainfall. In this region, most of the indicators focused on the appearance, movement and type of clouds; wind direction and temperature; and the movement and sound of insects, birds and other animals, as well as livestock behaviour. Plant and astrological indicators were used less frequently in Narok North.

In Narok North, farmers largely depended on weather information for agricultural decisions, particularly for rainfall information. Local weather Forecast Knowledge was found to be a crucial source of weather information in Narok North in the form of local ecological indicators and the local weather calendar. The majority of the farmers preferred using a mix of local and scientific knowledge or solely local knowledge. The use of scientific weather forecasting was less common.

Farmers recognised the value of more and better weather information but faced challenges in accessing these forecasts. Farmers' experiences with the DROP app were largely positive, with many finding it easy to navigate and highlighting the accuracy of the predictions. According to the farmers, integrating local knowledge in the DROP app increases the credibility, understandability and accuracy of the forecast. Farmers suggested the app is beneficial for agricultural activities such as land preparation, planting, fertilizer application, pest control, weeding, harvesting and crop selection. Farmers saw potential in the tool to enhance their decision-making and with the combat climate change, although challenges such as internet access and limited resources need to be addressed.

Integrating Local weather Forecast Knowledge into weather and climate information services, particularly the DROP app, has the potential to enhance smallholder farmers' ability to cope with climate change in Narok North, Kenya. Farmers heavily rely on local weather forecasting, with meteorological and animal indicators being dominant. These ecological indicators provide valuable insights into the local weather and are perceived as accurate. Integrating this knowledge into the DROP app can enhance the credibility, understandability and accuracy of weather forecasts in the region, potentially increasing the uptake of this weather information. Although challenges remain, climate resilience can be improved by strengthening informed agricultural decision-making while accounting for smallholder farmers' knowledge.

10. Literature

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Appendices

Appendix A DROP App Guide

The figures are retrieved from Lefèvre (2022) and the guide is adapted from Lefèvre (2022).

DROP App guide

The DROP app is designed to offer users rainfall forecasts based on local and scientific knowledge. The user may submit their daily rainfall forecast for the following day based on local ecological rainfall indicators, as well as their rainfall observations from the previous day. The scientific rainfall prediction is provided for 1, 7, or 14 days, based on the location of the field selected by the user.

Section 1: Download the app

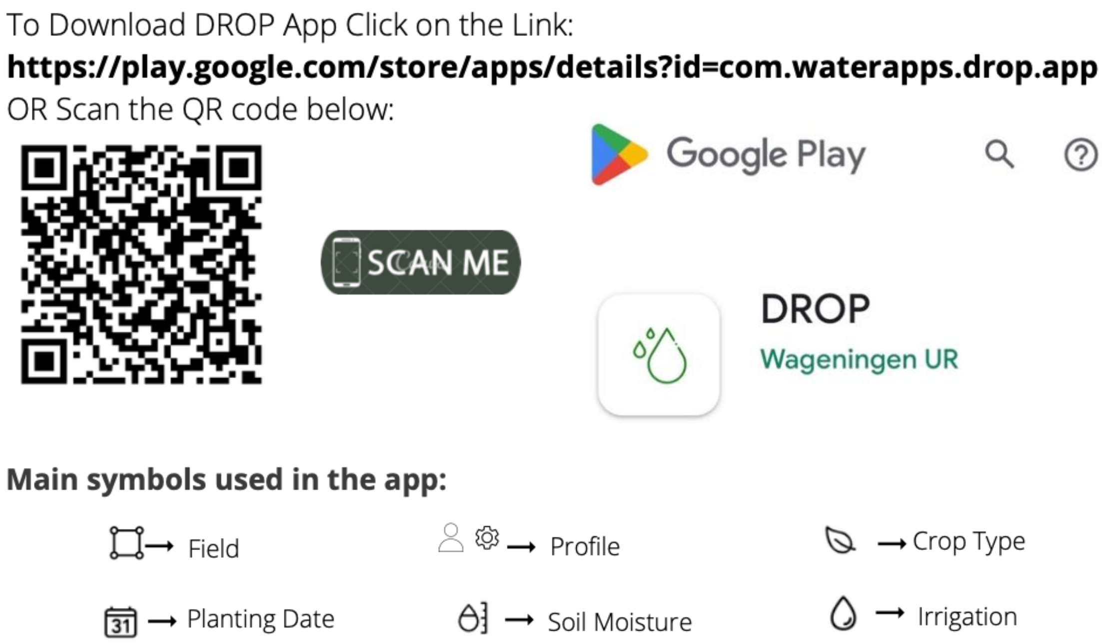

Figure A 1 Icon and QR code for the DROP app in Google Play Store, along with an illustration of the Main Symbols in the App (Figure adapted from Lefèvre (2022))

Section 2: Register and log in to App

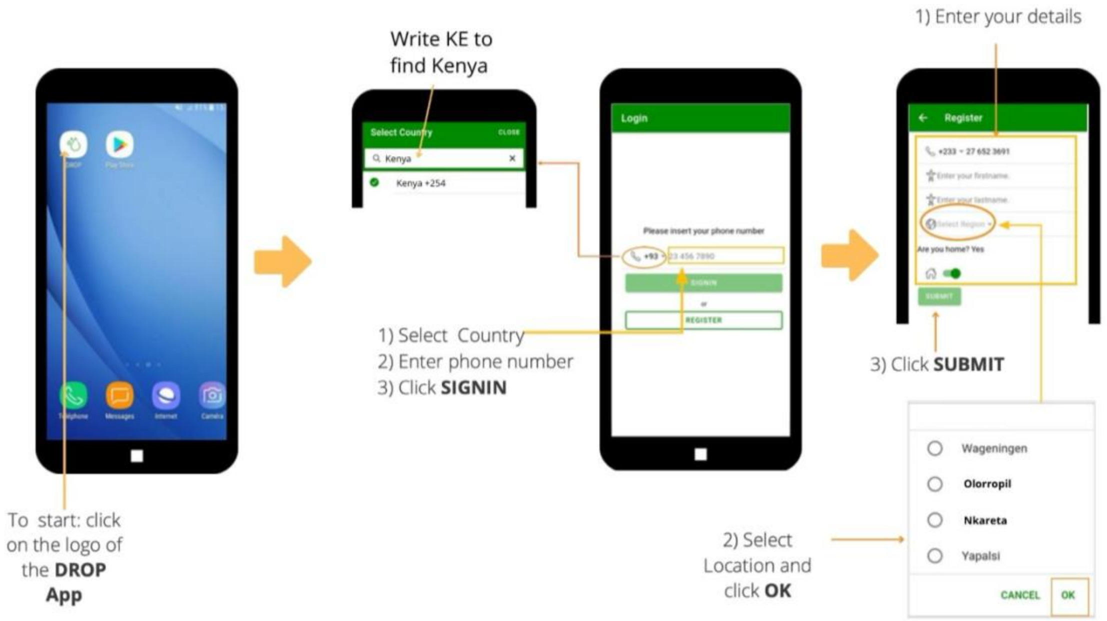

Figure A 2 Screenshots of the DROP App Interface: Demonstrating the Steps to register and log in to the App (Figure adapted from Lefèvre (2022))

Section 3: Create or add a farm field

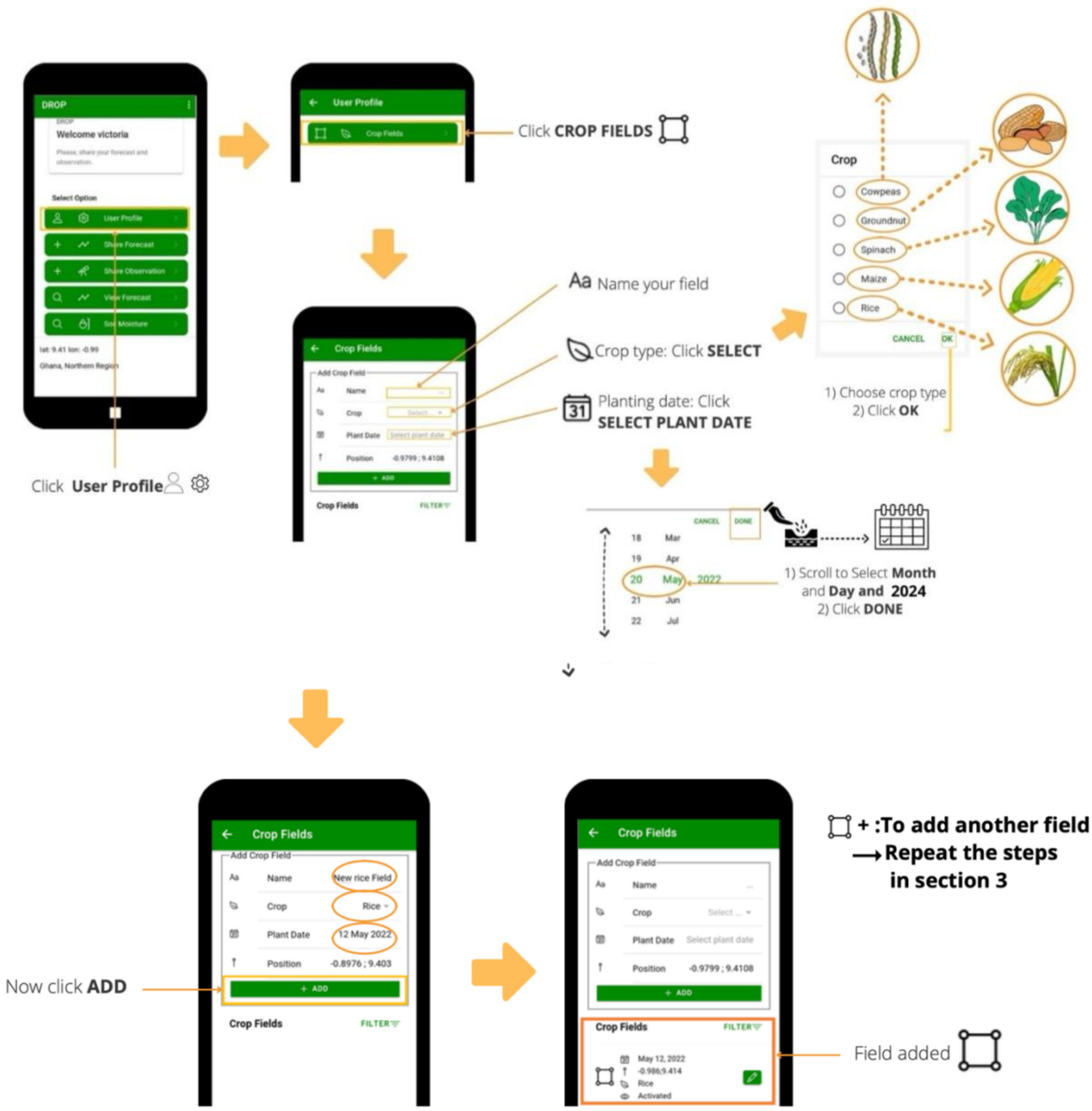

Figure A 3 Screenshots of the DROP App Interface: Demonstrating the Steps to create or add a farm field (Figure adapted from Lefèvre (2022))

Section 4: Edit and filter fields

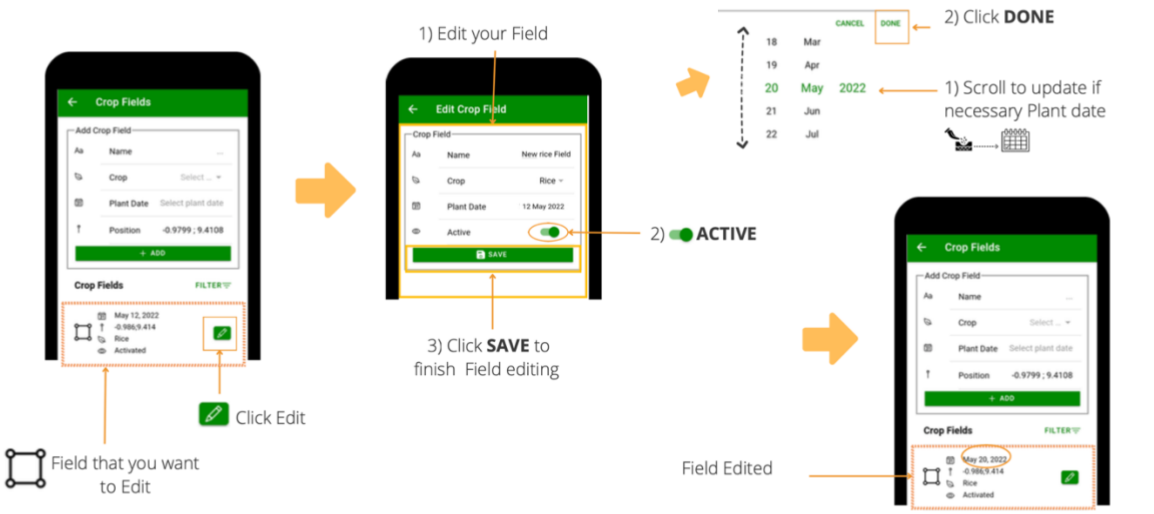

Figure A 4 Screenshots of the DROP App Interface: Demonstrating the Steps to Edit and Filter Farm Fields (Figure adapted from Lefèvre (2022))

Section 5: Scientific Rainfall Forecast

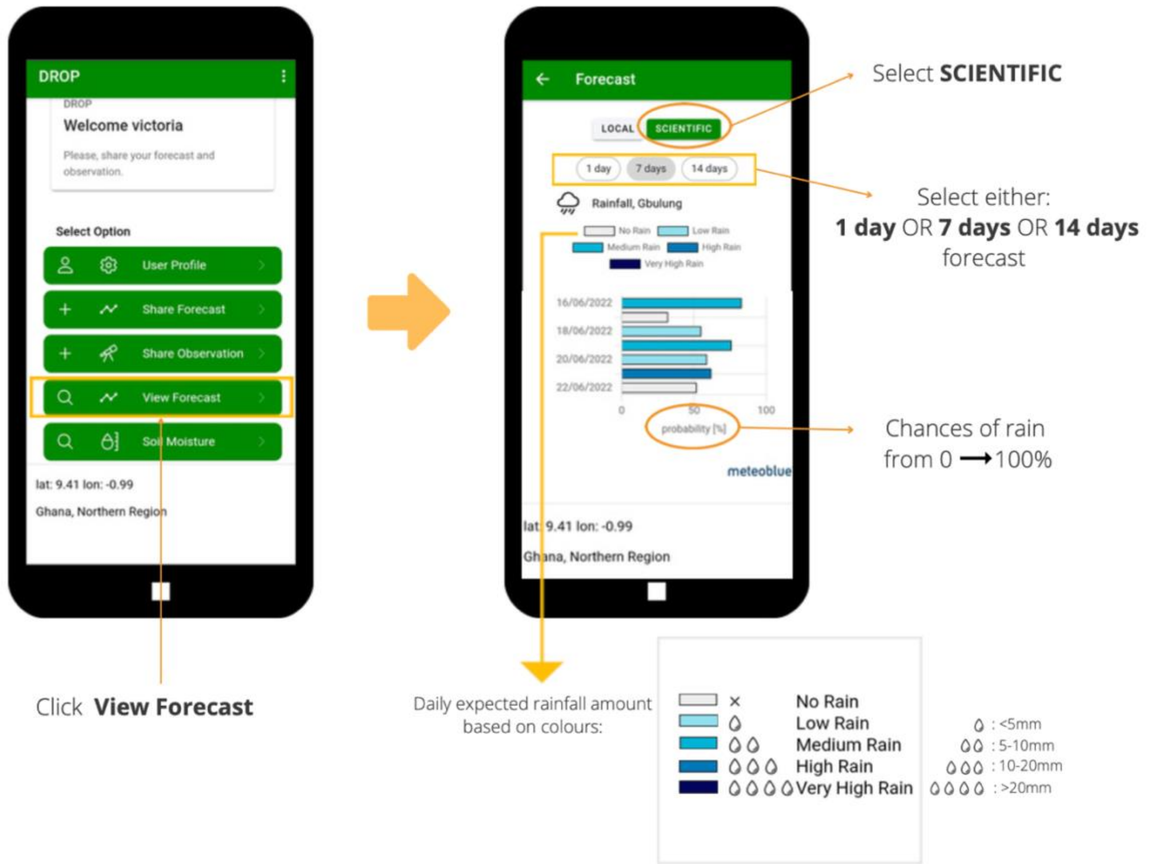

Figure A 5 Screenshots of the DROP App Interface: Demonstrating the Steps to show the Scientific Rainfall Forecast and the Interpretation of the Scientific Rainfall Forecast (Figure adapted from Lefèvre (2022))

Section 6: Share your Rainfall Forecast for Today before 8:00AM

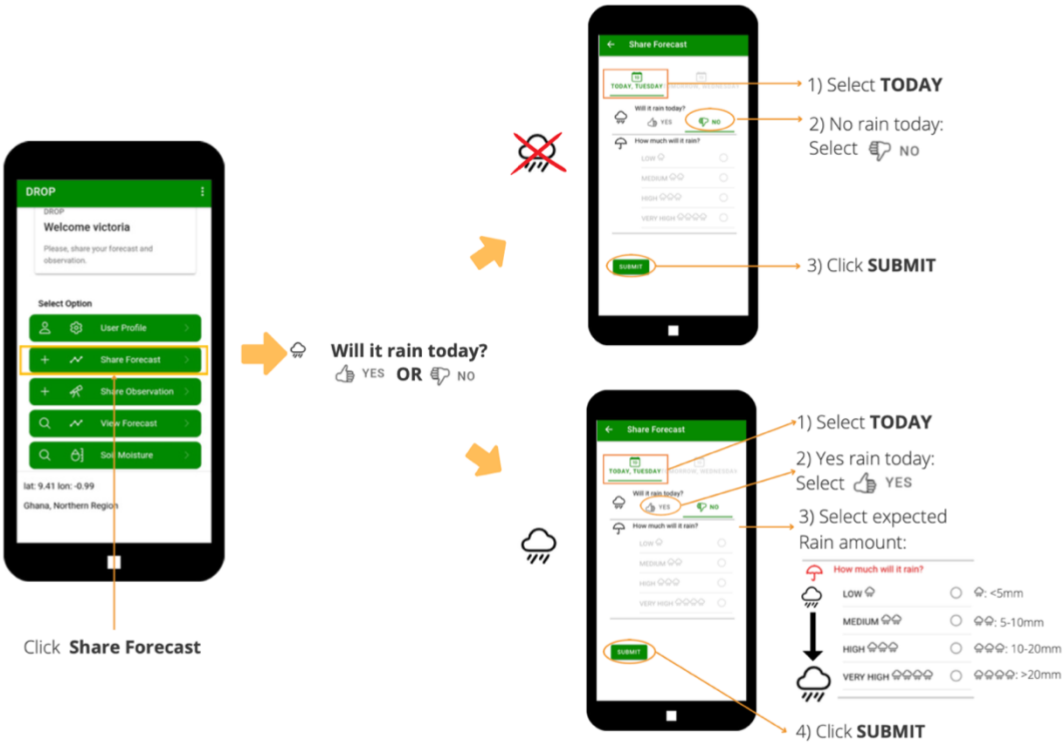

Figure A 6 Screenshots of the DROP App Interface: Demonstrating the Steps to share the Local Rainfall Forecast for Today (Figure adapted from Lefèvre (2022))

Section 7: Share your rainfall forecast for tomorrow

Figure A 7 Screenshots of the DROP app Interface: Demonstrating the Steps to share the Local Rainfall Forecast for Tomorrow (Figure adapted from Lefèvre (2022))

Section 8: Share rainfall observation of yesterday

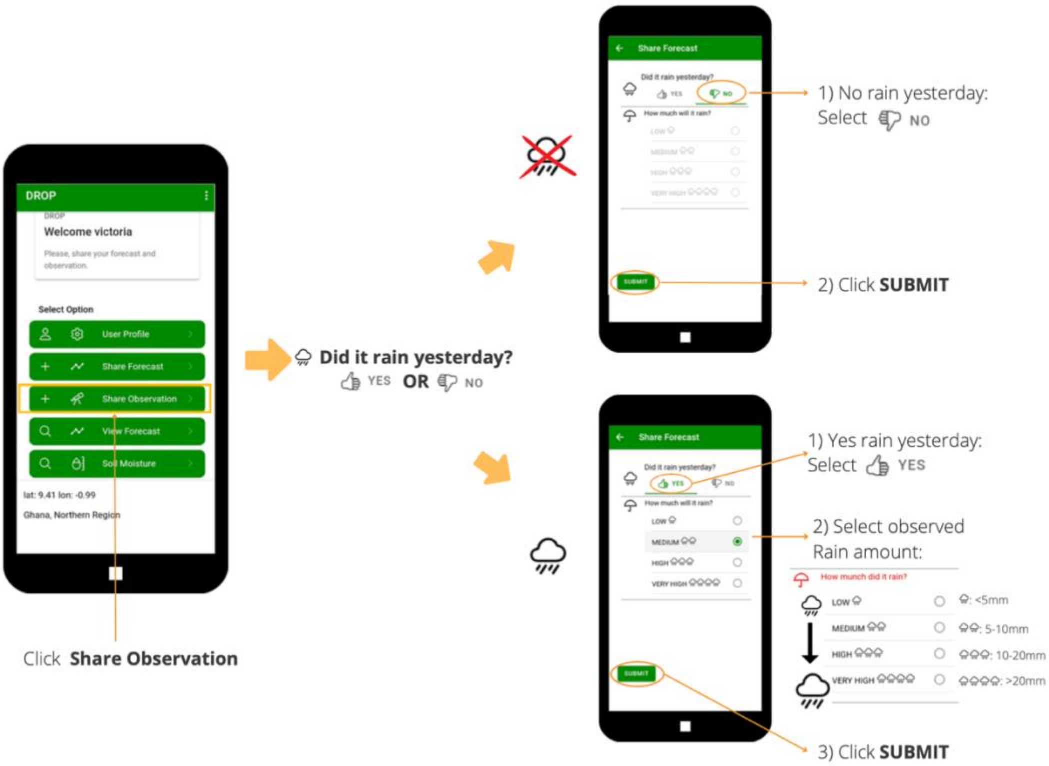

Figure A 8 Screenshots of the DROP App Interface: Demonstrating the Steps to share the Local Rainfall Observation of Yesterday (Figure adapted from Lefèvre (2022))

Section 9: Local rainfall forecast based on section 7 and 8

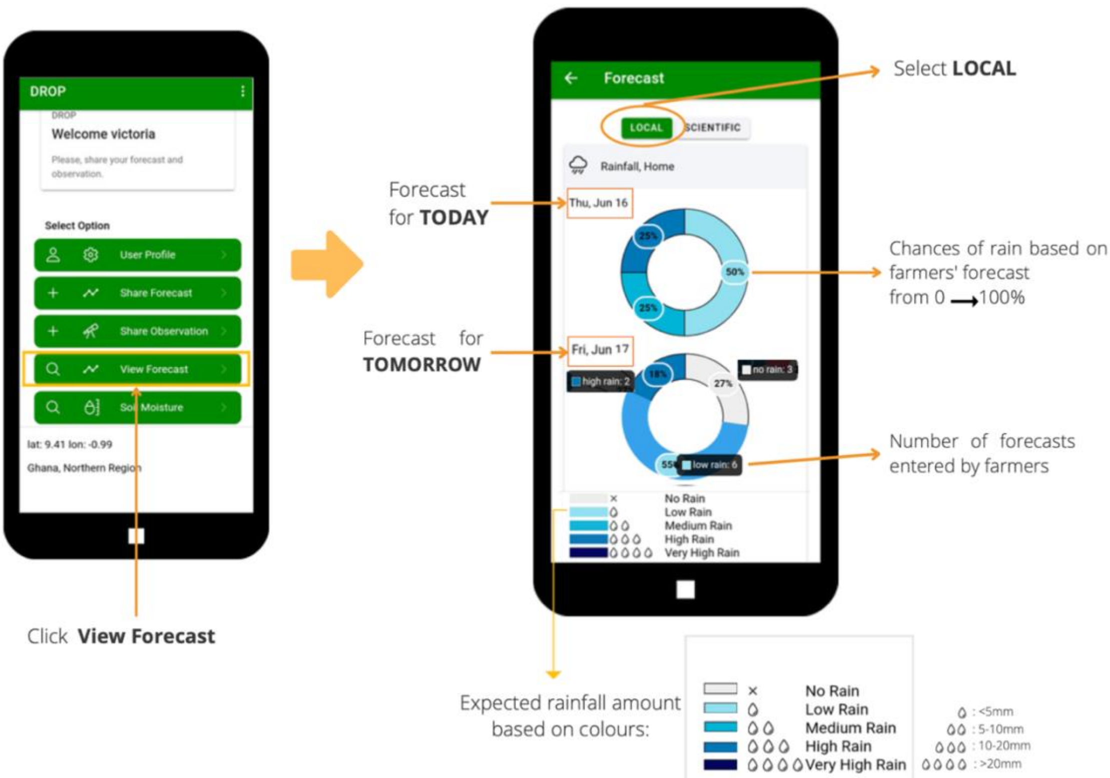

Figure A 9 Screenshots of the DROP App Interface: Demonstrating the Steps to View the Local Rainfall Forecast and the Interpretation of the Local Rainfall Forecast (Figure adapted from Lefèvre (2022))

Appendix B Systematic Literature Review

Table B 1 The Database and Search Strings used in the Systematic Literature Review, including the Number of Articles found for each Search String

Database	Search query			Number of articles
Google Scholar	Local forecast knowledge	AND	Kenya	10
	Local forecast knowledge	AND	Eastern africa	0
	Local forecast knowledge	AND	Sub-Saharan Africa	9
	Local weather Forecast Knowledge	AND	Kenya	3
	Local weather Forecast Knowledge	AND	Eastern Africa	0
	Local weather Forecast Knowledge	AND	Sub-Saharan Africa	4
	Local weather predictions	AND	Kenya	35
	Local weather predictions	AND	Eastern africa	7
	Local weather predictions	AND	Sub-Saharan Africa	40
	Indigenous forecasting knowledge	AND	Kenya	26
	Indigenous forecasting knowledge	AND	Eastern africa	4
	Indigenous forecasting knowledge	AND	Sub-Saharan Africa	10
	Traditional Forecasting Knowledge	AND	Kenya	33
	Traditional Forecasting Knowledge	AND	Eastern africa	1
	Traditional Forecasting Knowledge	AND	Sub-Saharan Africa	11

Table B 2 Overview of the Articles included in the Systematic Literature Review including the Lead Author, Study Design, Study Area and Sample Size

Author	Study design	Study area	Sample size
Kagunya et al. (2016)	Questionaires, 2 Focus Group Discussions	Isiolo County, Kenya	400 households (questionnaires), 2x10 Focus Group Discussion participants
Kipkorir et al. (2012)	Questionaires, Key Informant Interviews	Lake Victoria Basin, Kenya	240 individuals (questionnaires), 4 Key informant interviews
Paparrizos et al. (2023a)	Systematic Literature Review	Global	105 articles
Speranza et al. (2010)	Household Questionaires, Key Informant Interviews, Focus Group Discussions	Makueni County, Kenya	127 households (questionnaires)
Vervoort et al. (2015)	Questionaires, Focus Group Discussions, Key informant interviews	Laikipia County, Kenya	111 individuals (questionnaires), 24 Focus Group Discussion
		Vihiga County, Kenya	133 individuals (questionnaires), 24 Focus Group Discussion Participants

Appendix C Baseline Survey

SAFE4ALL Questionnaire (modified)

Safe4All is a project that aims to support farmers in Africa by making weather information easily usable. This questionnaire is a part of the Safe4All project. All personal information will be treated in the strictest confidence and will be used for research purposes only.

Do you agree to participate in this study?

☐ Yes
☐ No

Name of the recorder:

Location (GPS):

SECTION 1 – PERSONAL INFORMATION

In which ward of Narok North is your farm located?

☐ Olposimoru
☐ Olokurto
☐ Narok town
☐ Nkareta
☐ Olorropil
☐ Melili

1.1 What is your gender?

☐ Male
☐ Female
☐ Other

1.2 What is your age?

1.3 What is your level of education?

☐ No formal education
☐ Primary education (primary school)
☐ Secondary education (middle/high school)
☐ Tertiary education (university)

1.4 What is your literacy level?

☐ High
☐ Medium
☐ Beginner level
☐ None

1.5 How many members are there in the household?

1.6.1 How many male members are engaged in farming activities?

1.6.2 How many female members are engaged in farming activities?

1.7 How long have you been involved in farming activities/farming experience (in years)?

☐ Less than 10 years
☐ 10-20 years
☐ 21-30 years
☐ More than 30 years

1.8.1 Other than farming, do you have any other source(s) of income?

☐ Yes
☐ No

1.8.2 If yes, what is/are these source(s)?

SECTION 2 -AGROCNOMIC ACTIVITIES

2.1 Did you observe changes in the weather in the past 10 years?

☐ Changes in rainfall season start/end dates
☐ Droughts
☐ Increase in temperature
☐ Heavy wind
☐ Others, namely: ...

2.1.1 What other changes did you observe in the past 10 years?

2.2 Main crops (you can add another crop by clicking on the plus down below)

What crop do you cultivate?
What is the cultivation area of this crop (in acres)?
What is the planting time of this crop (week/month)?
What is the harvest time of this crop (week/month)?
Do you face crop failure with this crop? ☐ Every year ☐ Every 2 to 3 years ☐ Rarely ☐ Never
What do you think are the reasons for this crop to fail? ☐ Soil fertility ☐ Pests ☐ Water shortage ☐ Other, namely: ...
You mentioned there is another reason for the crop to fail, what is this reason?
+

2.3 Do you cultivate any other crops than already mentioned? If yes, how many acres and what is the yield?

2.4 Do you practice multi-cropping or multi-farming systems? If yes, what are they?

multi-cropping is when you produce different crops within one season. Multi-farming is when you also have other farming activities, such as livestock, beekeeping, or fisheries.

SECTION 3 – CURRENT ACCESS AND USE OF WEATHER INFORMATION

3.1 Do you use weather information for your farming decisions?

☐ Yes
☐ No

3.2 How do you get weather information? (You can choose more than one option)

☐ Local knowledge (ecological indicators)
☐ Local weather calendar
☐ Personal experience
☐ Personal/group measurement
☐ Agricultural extension officers
☐ Radio (local/national/international)
☐ Television (local/national/international)
☐ Newspaper (local/national/international)
☐ Mobile (SMS, voice call)
☐ Social media (WhatsApp, Telegram, Facebook, etc.)
☐ News or weather websites
☐ Mobile weather application (downloaded apps)
☐ Other, namely: ...

3.3 If you use local knowledge, what are the ecological indicators you observe? (You can choose more than one option)

☐ Birds' movements and sounds
☐ Insect movement and sounds
☐ Other animals' movements and sounds
☐ Clouds
☐ Wind
☐ Thunder and lightning
☐ Behavior of livestock
☐ Moon/sun/stars
☐ Flowering
☐ Temperature change
☐ Other, namely: ...

3.4 What weather information do you follow? (You can choose more than one option)

☐ Temperature
☐ Rainfall
☐ Wind information
☐ Other, namely: ...

3.5 How often do you consult weather information for managing your farm? (You can select more than one answer)

☐ Daily
☐ Every 2-3 days
☐ Weekly
☐ Monthly
☐ Seasonally
☐ Yearly
☐ Not at all

3.6 Which source of information on weather and climate do you prefer?

☐ Local knowledge (ecological indicators)
☐ Local weather calendar
☐ Personal experience
☐ Personal/group measurement
☐ Agricultural extension officers
☐ Radio
☐ Television
☐ Newspaper
☐ Mobile
☐ Social media
☐ News or weather websites
☐ Mobile weather application
☐ Other, namely: ...

3.7 Which source of information on weather and climate do you trust the most?

☐ Local knowledge (ecological indicators)
☐ Local weather calendar
☐ Personal experience
☐ Personal/group measurement
☐ Agricultural extension officers
☐ Radio
☐ Television
☐ Newspaper
☐ Mobile
☐ Social media
☐ News or weather websites
☐ Mobile weather application
☐ Other, namely: ...

SECTION 4 – WEATHER, CLIMATE, AND FARM DECISION-MAKING NEEDS

4.1 Did you adjust your farming based on the changing weather observed in recent years? Do you do something different than 5 years ago?

☐ Yes
☐ No

4.2 Are you currently thinking of changing your farming in the future because you think the weather will change?

☐ Yes
☐ No

4.3 Do you think weather and climate information is important for your farm management decisions?

☐ Strongly agree
☐ Agree
☐ Somewhat agree
☐ Disagree
☐ Strongly disagree
☐ I don't know

SECTION 5 – ACCESS TO TECHNOLOGY (MOBILE PHONE AND SOCIAL MEDIA PLATFORMS

5.1 Do you use a mobile phone?

☐ Yes

☐ No

5.1.1 If yes, is your mobile phone a smartphone?

☐ Yes

☐ No

5.2 Do you have access to/budget for the internet?

☐ Yes

☐ No

5.3 Do you use social media platforms to get information for farm decision-making?

☐ Yes

☐ No

5.4 How often do you use social media?

☐ Multiple times a day

☐ Daily

☐ Weekly

☐ Rarely

☐ Never

SECTION 6 – CLIMATE LITERACY AND EDUCATION

6.1 Do you have knowledge about climate change and its potential impacts on agriculture?

☐ I have extensive knowledge

☐ I have basic knowledge

☐ I have limited knowledge

☐ I do not have any knowledge at all

6.2 Are you interested in learning more about climate change and its potential impacts on agriculture?

☐ Yes

☐ Maybe

☐ No

This is the end of the questionnaire. Thank you for participating in the study!

Appendix D Interview Guide Semi-Structured Interviews Farmers

This interview is conducted as part of the data collection process for the development of Master Thesis for the fulfilment of the degree of Master of Science in International Land and Water Management at Wageningen University & Research in the Netherlands. The Research is focused on Local Weather Forecast Knowledge in Narok North. The interview takes approximately 5 minutes. You have the right to stop the interview at any time without any consequences.

Do you agree to participate?

1. What is your gender?
2. What is your age?
3. In which ward of Narok North is your farm located?
4. What local weather knowledge indicators do you observe to predict the weather?
5. What does this indicator predict?
6. Can you explain how this indicator works in practice?
7. How many days in advance does it predict rain?
8. Does it predict rainfall seasons? If yes, onset of the short or long rains?

Appendix E Monitoring Questionnaire DROP app and Focus Group Discussion Questions

Monitoring Questionnaire DROP app

Farmer information

1. **Gender: ________________________________**
2. **Name of your village: _____________________**
3. **Age: ____________________________________**
4. **Main crops: _____________________________**
5. **Number of Acres of farmland: _____________**

! PLEASE INDICATE YOUR ANSWER BY CIRCLING ONE OPTION !

Use of the app:

2. **Did you use the app since the last workshop?**

   Yes / No

3. **In general, how has it been to use and navigate through the app?**

   Very easy / easy / moderate / somewhat difficult / very difficult

4. **How many times have you used the app since the last workshop?**

   Multiple times a day / Daily / Once every 2 days / Once every 3 days / Once / Never

5. **How often have you used the app to share your local forecast and observation?**

   Daily / Once every 2 days / Once every 3 days / Once every 4 days / Once every 5 days / Once every 6 days / Once a week / Never

Rainfall forecast:

6. **How often have you used the app to check the rainfall forecast?**

   Multiple times a day / Daily / Once every 2 days / Once every 3 days / Once / Never

7. **Which rainfall forecast did you use the most?**

   Local forecast / Scientific forecast / Combination of both

8. **Which part of the scientific forecast did you use the most?**

   1-day forecast / 7-day forecast / 14-day forecast / combination of all of them

9. **How accurate do you perceive the local forecast was?**

   Very poor / poor / acceptable / good / very good

10. **How accurate do you perceive the scientific forecast was?**

    Very poor / poor / acceptable / good / very good

Combatting climate change

11. **Has the rainfall forecast information helped you in agricultural decisions? Indicate your answer for each activity,** if you have any other additional activities, you can add them)

    (Rate on a scale from 1 to 5: (1 = not helpful at all, 5 = extremely helpful)

Activity	**Rating**	**Explanation**
Land preparation	1 / 2 / 3 / 4 /5	
Planting	1 / 2 / 3 / 4 /5	
Applying fertilizers	1 / 2 / 3 / 4 /5	
Applying chemical/ pest control	1 / 2 / 3 / 4 /5	
Weeding	1 / 2 / 3 / 4 /5	
Harvesting	1 / 2 / 3 / 4 /5	
Choice of crop	1 / 2 / 3 / 4 /5	

12. **Do you feel like the app has helped or can help increase the awareness of climate conditions? Rate on a scale from 1 to 5: (1 = not helpful at all, 5 = extremely helpful)**

    1 / 2 / 3 / 4 / 5

13. **Do you feel like the app has helped or can help you to prepare for rainfall variability?**

    Rate on a scale from 1 to 5: (1 = not helpful at all, 5 = extremely helpful)

    1 / 2 / 3 / 4 / 5

14. **Do you feel like the app has helped or can help you to prepare for droughts?**

    Rate on a scale from 1 to 5: (1 = not helpful at all, 5 = extremely helpful)

    1 / 2 / 3 / 4 / 5

15. **Do you feel like the app has helped or can help you to prepare for extreme rainfall?**

    Rate on a scale from 1 to 5: (1 = not helpful at all, 5 = extremely helpful)

    1 / 2 / 3 / 4 / 5

16. **Do you feel the app can help you create a more sustainable and climate resilient farm?**

    Not at all / a little / moderately / significantly / very significantly

<u>Integrating local knowledge</u>

17. **Do you feel like the combination of LFK and SFK improves the accuracy of the forecast?**

    Not at all / a little / moderately / significantly / very significantly

18. **Indicate your level of trust in the different forecasts (On a scale from 1 to 5) (1 = I don't trust it at all, 5 = I really trust it)**

    Local forecast 1 / 2 / 3 / 4 / 5

    Scientific forecast 1 / 2 / 3 / 4 / 5

    Combination of the forecasts 1 / 2 / 3 / 4 / 5

19. **Do you think that integrating the local forecast makes the app more relevant for your specific farm conditions?**

    Not at all / a little / moderately / significantly / very significantly

20. **Has the element of the forecast based on local knowledge encouraged you to use the app?**

    Yes/ a little / No

Explain why:

21. **Do you think the element of the forecast based on local knowledge could encourage others to use the app?**

    Yes/ a little / No

Explain why:

Sharing the information and app

22. **Have you shared the rainfall o forecasts from the app to other farmers?**

    Yes / No

23. **Would you recommend the app to other farmers?**

    Yes / No

24. **Would you be willing to pay for this app?**

    Yes / No / I am not sure

Focus Group Discussion Questions

1. What aspects of the DROP app do you like?
2. What aspects of the DROP app do you not like? (challenges)
3. In what way does the DROP app support your agricultural decision-making?
4. What additional/other information could the drop app include to better support your agricultural decision-making?
5. How do you think the inclusion of local forecasts could encourage use among farmers? (what is the added value of it)
6. How can the DROP app help deal with climate change?

Appendix F Interview Guides Key informant Interviews

Interview Guide Agricultural Extension Officers

Name of the participant:

Represented institution:

Date and time:

Place:

This interview is conducted as part of the data collection process for the development of Master Thesis for the fulfilment of the degree of Master of Science in International Land and Water Management at Wageningen University & Research in the Netherlands. The research is conducted in partnership with the Jomo Kenyatta University of Agriculture and Technology (JKUAT). This study is under the SAFE4ALL Africa project. The information provided will be used for scientific reports which will be publicly available. You have the right to stop the interview at any time without any consequences.

<u>Section 1 Climate change and agriculture</u>

1. How is climate change influencing the weather patterns in Narok County, especially Narok North?
2. What are the implications of hydroclimatic variability because of climate change in the agricultural activities in Narok North, Kenya?

<u>Section 2 Agricultural practices</u>

3. Which are the agroecological zones in Narok North? How is the climate distributed in the different wards?
4. Which are the main crops in each ward?
5. What are the gender roles in agriculture in Narok North? Which are the tasks of male and female farmers?
6. Which are the main challenges of the farmers in Narok North? Which are the challenges of male and female farmers?

<u>Section 3 Weather and climate information</u>

7. Do you use weather and climate information for your tasks as extension officer?
8. How do you get the weather and climate information? Are you in contact with the climate and weather information producer?
9. How do you translate the weather and climate information to the end-users (smallholder farmers)?
10. What are the limitations of the scientific weather forecast knowledge (SFK)?
11. What are the main challenges you face as a scientific weather forecast user? In terms of accessibility, availability, accuracy, reliability.

<u>Section 4 Scientific and Local Weather Forecast Knowledge</u>

12. How do you perceive local weather forecast knowledge? How important do you think LFK is for smallholder farmers?

13. How can the combination of scientific weather forecast knowledge (SFK) and local weather forecast knowledge (LFK) solve the limitations of both types of forecasts?
14. What can be the challenges of using an agricultural app that integrates both SFK and LFK for smallholder farmers?

Section 5 Role of weather and climate information in small-scale agriculture

15. What kind of weather, climate, and farm related decisions do smallholder farmers need to make?
16. What role do weather and climate information services (WCISs) currently play in supporting agricultural decision-making of smallholder farmers?
17. What are the key barriers for smallholder farmers in accessing and effectively using WCISs? Please, specify the barriers for male and female farmers in terms of accessibility, credibility, availability, understandability, among others. How could those barriers vary across zones in Narok? How could these barriers be overcome?
18. In the future, what role could WCISs play in helping smallholder farmers better cope with climate change? Specifically, what could the role be of a WCIS that integrates both LFK and SFK?
19. Which specific climate hazards do you think smallholder farmers could manage better if they use WCISs?

Interview Guide Meteorological Department

Name of the participant:

Represented institution:

Date and time:

Place:

This interview is conducted as part of the data collection process for the development of Master Thesis for the fulfilment of the degree of Master of Science in International Land and Water Management at Wageningen University & Research in the Netherlands. The research is conducted in partnership with the Jomo Kenyatta University of Agriculture and Technology (JKUAT). This study is under the SAFE4ALL Africa project. The information provided will be used for scientific reports which will be publicly available. You have the right to stop the interview at any time without any consequences.

Section 1. Role in the organisation

1. Can you tell us something about the institution you work for?
2. What is your role within your institution?

Section 2 Climate change impact and agriculture

3. How is climate change influencing the weather patterns in Narok County, especially Narok North?
4. What are the implications of hydroclimatic variability because of climate change in the agricultural activities in Narok, Kenya?

5. Which are the agroecological zones in Narok (North)? How is the climate distributed in the different wards?

<u>Section 3 Scientific weather and climate information</u>

6. What kind of weather forecast information do you produce? How often do you produce it? Who is the end-user?
7. What kind of climate change projections do you produce? How often do you produce it? Who is the end-user?
8. Are you in contact with the end-user? Or are they in any way able to communicate their preferences?
9. How do you translate the weather and climate information to the end-users (smallholder farmers)?
10. What are the limitations of the scientific weather forecast knowledge (SFK)?
11. What are the main challenges you face as a scientific weather forecast producer?

<u>Section 4 Scientific and local weather forecast knowledge</u>

12. How do you perceive local weather forecast knowledge? How important do you think LFK is for smallholder farmers?
13. How can the combination of scientific weather forecast knowledge (SFK) and local weather forecast knowledge (LFK) solve the limitations of both types of forecasts?
14. What can be the challenges of using an agricultural app that integrates both SFK and LFK for smallholder farmers?

<u>Section 5. Role of weather and climate information in small-scale agriculture</u>

15. What role do weather and climate information services (WCISs) currently play in supporting agricultural decision-making of smallholder farmers?
16. What barriers exist for smallholder farmers in using WCISs? (accessibility, credibility, availability, understandability)
17. In the future, what role could WCISs play in helping smallholder farmers better cope with climate change?
18. Which specific climate hazards do you think smallholder farmers could manage better if they use WCISs?

Appendix G Local Weather Forecast Knowledge Indicators in Kenya

Table G 1 Local Weather Forecast Knowledge Indicators within the Main Category Animal Indicators used in Kenya as identified in the Systematic Literature Review with relevant Sub-Categories Identified, categorized by area (Based on Kagunyu et al. (2016), Kipkorir et al. (2012), Paparrizos et al. (2023a), Speranza et al. (2010) and Vervoort et al. (2015))

Indicator main category	Indicator (Sub-Category)	**Laikipia County**	**Vihiga County**	**Isiolo County**		**Makueni County**		**Lake Victoria Basin**
	Forecast of indicator	rainfall onset	rainfall onset	drought	rainfall onset	drought	Non-drought	rainfall onset
ANIMAL	**Combination of animals**					Yes		Yes
	Animal noise							Yes
	Direction of migration of birds and bees					8.0%	5%	
	Appearance of rare birds/insects					8.0%		
	Disappearance of certain birds/insect species					1.0%		
	Millipedes, Kaunga birds, crickets making Noise at night					5.0%		
	Insect Movements and sounds	**Yes**	**Yes**	**Yes**		**Yes**		**Yes**
	Migration of butterflies	3.0%	2.7%					
	Appearance of certain ants	4.5%	0.9%			2.0%		Yes
	Appearance of dragon flies/butterflies/other insects				Yes		2%	Yes
	No abnormal events like locust invasion						1%	
	Presence of too much honey in the beehives					1.0%		
	Bird Movements and Sounds	**Yes**	**Yes**	**Yes**		**Yes**		**Yes**
	Migration of birds							Yes
	Appearance of many birds in groups						5%	
	Birds movement			12.0%	16.0%			
	Birds singing	7.2%	8.1%	12.0%	16.0%			
	Livestock Behaviour	**No**	**No**	**Yes**		**Yes**		**Yes**
	Livestock excitement							Yes
	Animals get restless, Not sleeping and sitting, unsettled and disappear into the bush until sunset			Yes				
	Poultry, cattle looking weak all the time					10.0%		
	Livestock refuses to get up				Yes			
	Intestines of slaughtered animals turn red for rain onset				Yes			
	Intestines of slaughtered animals turn black for drought			41.0%				
	Other animal movements and sounds	**Yes**	**Yes**	**Yes**		**Yes**		**Yes**
	Domestic animals refuse to enter sheds				Yes			
	Croak of frogs	6.0%	17.1%					
	Frogs fail to croak					1.0%		
	Invasion of wild animals in the area					1.0%		
	Many wild animals attacking germinating crops						3%	

Table G 2 Local Weather Forecast Knowledge Indicators within the Main Category Meteorological Indicators used in Kenya as identified in the Systematic Literature Review with relevant Sub-Categories Identified, categorized by area (Based on Kagunyu et al. (2016), Kipkorir et al. (2012), Paparrizos et al. (2023a), Speranza et al. (2010) and Vervoort et al. (2015))

Indicator main category	Indicator (Sub-Category)	**Laikipia County**	**Vihiga County**	**Isiolo County**		**Makueni County**		**Lake Victoria Basin**
	Forecast of indicator	rainfall onset	rainfall onset	drought	rainfall onset	drought	Non-drought	rainfall onset
METEOROLOGICAL	**Clouds**	**Yes**	**Yes**	**Yes**		**Yes**		**Yes**
	Observations of the sky			4.5%				
	Formation and movement of clouds	14.3%	21.6%			2.0%		Yes
	Cloudy sky						1%	
	Appearance of nimbus/cumulus/dark/small/few clouds on the sky	Yes	Yes				12%	Yes
	Appearance of nimbus clouds during the day and disappearing at night					Yes		
	Clearness of sky			Yes		8.0%		
	Wind	**Yes**	**Yes**	**No**		**Yes**		**Yes**
	Wind direction	65.4%	57.0%					Yes
	Wind blows from Mt kilimanjaro and back						1%	
	Wind timing							Yes
	Wind strength							Yes
	Very strong wind blowing					6.0%	1%	
	Sun	**No**	**No**	**No**		**Yes**		**No**
	Position of the sun					1.0%		
	Shading of the sun						1%	
	Shadow of Maluini hills changes in the Normal position					1.0%		
	No shading of the sun					1.0%		
	Temperature	**Yes**	**Yes**	**Yes**		**Yes**		**No**
	High temperatures	6.0%	4.5%	16.0%			13%%	
	Unusual high temperatures at night	Yes	Yes					
	Very hot/sunny					6.0%		
	Cooler than Normal	0.0%	3.6%			5.0%		
	Cool atmosphere						9%	
	Dew	**No**	**Yes**	**No**		**Yes**		**No**
	Presence of dew in the morning					1.0%		
	Unusual morning dew after a dry season		12.9%					
	Mist	**No**	**No**	**No**		**Yes**		**No**
	Presence of mist during dry season					8.0%		
	Thunder and lightening	**No**	**Yes**	**No**		**Yes**		**Yes**
	Presence of thunderstorms		5.4%			1.0%	4%	
	Lightening becomes rare					1.0%		
	Frequent lightening							Yes
	Lightening strikes vertical (rain onset)							Yes
	Lightening strikes horizontal (No rainfal onset soon)							Yes

Table G 3 Local Weather Forecast Knowledge Indicators within the Main Categories Astrological Plant and Other Indicators used in Kenya as identified in the Systematic Literature Review with relevant Sub-Categories Identified, categorized by area (Based on Kagunyu et al. (2016), Kipkorir et al. (2012), Paparrizos et al. (2023a), Speranza et al. (2010) and Vervoort et al. (2015))

Indicator main category	Indicator (Sub-Category)	**Laikipia County**	**Vihiga County**	**Isiolo County**		**Makueni County**		**Lake Victoria Basin**
	Forecast of indicator	rainfall onset	rainfall onset	drought	rainfall onset	drought	Non-drought	rainfall onset
ASTROLOGICAL	**Stars**	**No**	**No**	**Yes**		**Yes**		**Yes**
	Stars in general							Yes
	Sky is full of stars at night					4.0%		
	Few stars in the sky						3%	
	Constellation of the seven stars			11.5%	53.0%			
	Constellation of the seven stars appears in the east					1.0%		
	Constellation of seven stars remains at a central position						1%	
	Moon	**No**	**No**	**No**		**Yes**		**Yes**
	Moon in general							Yes
	Direction of movement of the moon						1%	
	Size and shape of the moon					3.0%		
	Circles around the sun and moon	**No**	**No**	**No**		**Yes**		**No**
	Appearance of circle/circles around the moon/the sun						5%	
	Appearance of a very small circle around the sun and no circle around the moon					1.0%		
PLANT	**Plants in general**	**Yes**	**Yes**	**Yes**		**Yes**		**Yes**
	Plants							Yes
	Leaves	**No**	**Yes**	**Yes**		**Yes**		**No**
	Changes in color of leaves		1.8%			3.0%		
	Falling/shedding of leaves		3.6%	15.0%		3.0%		
	Flowering/blossoming of trees and plants	**No**	**No**	**Yes**		**Yes**		**Yes**
	Trees fail to flower/blossom late					8.0%		
	Unusual shedding of the flowers of the mango tree						1%	
	Flowering of trees				31.0%	3.0%	15%	Yes
	Certain trees blossom too much					6.0%		
	Flowering of Muthiia tree						1%	
	Ripening of Thwaala						1%	
OTHER	**Other indicators**	**No**	**Yes**	**No**		**Yes**		**No**
	Water massess dry up earlier than usual					2.0%		
	Cooler water than normal		Yes					
	Calender readings: every year ending with 3 or 4 (e.g. 1983, 1994)					1.0%		
	Mt Kilimanjaro looks very dark						1%	
	When Mt. Kilimanjaro looks clear for a long time					1.0%		

Appendix H AI Statement

In this thesis, ChatGPT and Grammarly has been used to improve writing. AI assisted in grammar, coherence, clarity and structure of written text to ensure readability of the text. Additionally, ChatGPT has provided guidance in producing the Rstudio code to enhance the data analysis process. Suggestions of the tools were critically assessed and has solely been used supplementary to the original text and Rstudio code.