Towards Gender-Responsive Weather and Climate Information Services: An Evaluation of Local and Scientific Forecasts in Northern Ghana

A Gender Perspective on Weather and Climate Information

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Master Thesis Water Systems and Global Change Group in partial fulfilment of the degree of Master of Science in Climate Studies at Wageningen University, the Netherlands

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Abstract

Smallholder farmers engaged in rainfed agriculture require reliable weather and climate information to adapt to and mitigate the risks of climate change. However, the needs of women are under-represented in the development of many Weather and Climate Information Services (WCIS). Understanding gender-based differences in needs and access to weather and climate information is essential to develop WCIS that benefit men and women equally.

This study used a mixed-methods approach to assess information needs and access, indigenous knowledge of local indicators, local forecast skill, and forecast perception of farmers in Northern Ghana, using a gender perspective. The results of a semi-structured questionnaire, involving 60 farmers, show that while the information needs of male and female farmers largely correspond, differences exist in their access to this information. While farmers do not prefer local forecasts over scientific forecasts, they use local forecasts more frequently. Male farmers use forecast information more frequently than female farmers. Furthermore, men possess more indigenous knowledge of rainfall and soil moisture than women. Most of the documented rainfall indicators are only applied in Ghana, which indicates that WCIS based on indigenous knowledge cannot simply be copied from one country to another. The skill assessment showed that men are more skilled in predicting rainfall than women, but that both genders are unable to properly discriminate between rain/no rain. Therefore, both genders could greatly benefit from WCIS. Introducing farmers to the DROP app, a WCIS providing both local and scientific rainfall forecasts, has increased farmers' trust in both forecast types but decreased their perception of the forecasts' accuracies, which is likely linked to increased awareness of forecast accuracies. Farmers use the forecasts in their agricultural decision-making and daily activities. Both male and female farmers would like to receive an integrated forecast, derived from a combination of scientific and local forecasts.

Overall, this study highlights the importance of climate and weather information provision and the differences in indigenous knowledge and access to scientific information between male and female farmers. Future studies are necessary to complement this research by collecting more gender-disaggregated data, especially on the preferred channel for information dissemination and the long-term benefits of WCIS, and to collect gender-disaggregated data in other countries, particularly outside Sub-Saharan Africa.

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1 Introduction

1.1 Background

The adverse effects of human-induced climate change are widespread and apparent worldwide. However, the most vulnerable countries, such as countries in the Global South, are disproportionately affected (Frischmann et al., 2022; IPCC, 2022). Similarly, climate change is not gender-neutral either. Women are more vulnerable to the impacts of climate change and variability than men (Henriksson et al, 2021; Kowornu & Osei-Asara, 2019; Ngigi & Muange, 2022; Rao et al., 2019; UNDP, 2019; UN Women, 2022). With climate change, extreme events are projected to become more frequent and severe (Chang'a et al., 2010; Gbangou et al., 2021; IPCC, 2022). Overall, rainfall frequency is expected to decrease, whereas rainfall intensity and temperature are anticipated to increase (Dai et al., 2018; IPCC, 2022). This affects climate-sensitive sectors like agriculture and water, which endangers food and water security. Moreover, climate change exacerbates existing gender inequalities (Diouf et al., 2022; UN Women, 2022). These impacts threaten the achievement of the Sustainable Development Goals (SDGs) (IPCC, 2022; Radeny et al., 2019). Hence, it is essential to enhance the adaptive capacity of individuals who are most vulnerable to the impacts of climate change.

Demand for Accurate Rainfall Information

In the Global South, rainfed agriculture is a major contributor to both food security and the local economy (Sidibé et al., 2018). Farmers' livelihoods are directly dependent on the prevailing weather and climate conditions, making them vulnerable to the effects of climate change (Balehegn et al., 2019; Gbangou et al., 2021). As the farmers base their farming practices and the timing thereof on the expected weather (Sutanto et al., 2022), accurate weather forecasts are of utmost importance to make the right and timely decisions to produce a profitable yield (Chang'a et al., 2010; Kijazi et al., 2013). While scientific forecasts derived from numerical weather models are the primary means of obtaining weather and climate information in many developed countries, especially in the mid-latitudes, this is not the case in the Global South (Plotz et al., 2017). Instead, many farmers in the Global South rely on local forecasts based on indigenous knowledge to predict weather (Balehegn et al., 2019; Gbangou et al., 2021; Paparrizos et al., 2022; Plotz et al., 2017).

Farmers in the Global South do not widely use scientific precipitation forecasts for several reasons. Firstly, the accuracy of scientific forecasts is limited at the high spatial resolution needed for farm-level decision-making (Gbangou et al., 2021; Jiri et al., 2016). As the forecasts are often developed at a coarse spatial scale, the knowledge shared in the scientific forecasts is not tailored to the needs of the smallholder farmers (Gbangou et al., 2021; Nyadzi et al., 2022; Plotz et al., 2017). Secondly, farmers do not always accept scientific forecasts (Gbangou et al., 2021). This is partly because of a lack of farmer involvement in the development process and/or their lack of trust in forecast providers (Nyadzi et al., 2022; Paparizzos et al., 2022). Thirdly, some farmers struggle to comprehend and interpret the information because they do not comprehend the numbers or the communication language used (Balehegn, 2019; Plotz et al., 2017; Sutanto et al., 2022). For example, scientific rainfall forecasts are often given in probabilities, which many farmers find difficult to interpret. Fourthly, not everyone has access to scientific forecasts as these are not always disseminated via appropriate information channels (radio, TV, etc.) or communicated at the right time (Jiri et al., 2016; Plotz et al., 2017). Lastly, some farmers might be unable to afford the equipment necessary to access scientific forecasts (Balehegn et al., 2019).

Alternatively, smallholder farmers use local forecasts, which are more accessible and affordable. Local forecasts are based on traditional knowledge passed down over generations, past experiences, and observations of agro-meteorological indicators (Nyadzi et al., 2022). These local forecasts are vital for rural communities to protect the environment and cope with natural disasters like droughts (Chang'a et al., 2010). However, various challenges are related to local forecasting. Due to climate variability and change, the reliability of local forecasts is reduced and biological indicators may change (Balehegn et al., 2019; Chang'a et al., 2010; Jiri et al., 2016; Plotz et al., 2017). Moreover, due to land-use change, species used as traditional indicators may disappear. Furthermore, there is a lack of systematic documentation of local forecast indicators (Chang'a et al., 2010). Traditionally, knowledge is transferred from elder to young generations. However, due to the passing of elders, an emphasis on modern science and reduced reliability due to the effects of climate change, traditional knowledge is no longer passed on to the younger generation of farmers (Balehegn et al., 2019; Chang'a et al., 2010; Plotz et al., 2017). As the knowledge is not documented, it means that this knowledge is slowly forgotten. Furthermore, scientists and policymakers are sceptical about the local forecasts, as they are not based on scientific knowledge but on traditional ecological knowledge and spiritual beliefs that they do not understand (Nyadzi et al., 2022). Moreover, there are replicability issues, as the forecasts are based on relative and local experiences and observations (Chang'a et al., 2010; Gbangou et al., 2021). This means that the local forecasts in one region might not be applied in another region. Furthermore, there is a lack of research on the accuracy and reliability of local forecasts (Chang'a et al., 2010). An additional problem is that when both local and scientific forecast systems are available, users can get confused. When the weather information from different sources contradicts, it is complicated to make decisions on farming practices (Nyadzi et al., 2022).

Both scientific and local weather forecasts have strengths but also challenges that reduce the reliability of the information they provide in the Global South (Plotz et al., 2017). However, accurate and accessible weather information tailored to farmers' needs is required to assist in farm-level decision-making and will only become more crucial in the future due to climate change. Research shows that the incorporation of indigenous knowledge into scientific forecasting systems has the potential to substantially improve the communication of weather and climate information, especially for rural communities in remote areas (Gbangou et al., 2021; Nyadzi et al., 2022; Plotz et al., 2017; Radeny et al., 2019). Furthermore, it would enhance the spatial and temporal resolution of forecasts, making them more relevant to their users (Jiri et al., 2016). Users are more likely to believe and use the weather information when it is, in part, based on their knowledge and when it is relevant to them (Guido et al., 2020; Plotz et al., 2017). Therefore, there is a need for the development of a hybrid forecast, created by integrating local and scientific forecasts (Balehegn et al., 2019). The hybrid forecast could be shared through Weather and Climate Information Services (WCIS).

Demand for Soil Moisture Information

In addition to weather, e.g., precipitation, soil moisture is an important variable in agriculture (Sutanto et al., 2022). When there is either a water shortage or excess in the soil, crops may suffer from abiotic stress (Gałęzewski et al., 2021). Thus, soil moisture influences crop growth and thereby yield. Vice versa, the crop (type) also influences soil moisture (Asbjornsen et al., 2011). As soil moisture is a key component in agriculture and influences smallholders' livelihoods and food security, it should be considered in agricultural decision-making (Sutanto et al., 2022). However, soil moisture information is generally not included in the many WCISs that have been developed so far, partially because several challenges are hindering the development of a soil moisture module in WCIS (Sutanto et al., 2022). To overcome this gap, Sutanto et al. (*unpublished*) developed a simple WCIS with a soil moisture module (WCIS-SM), called the DROP app. The DROP app includes scientific weather forecasts provided by meteoblue, local forecasts, and a soil moisture forecast.

(Demand for) Integration of Gender in the Development of WCIS

As previously mentioned, women are more vulnerable to the impacts of climate change than men. This is caused by their greater household responsibilities, and lack of resources and political voice, amongst others (Partey et al., 2022; UN Women, 2022). However, it is imperative to stress that women should not only be seen as vulnerable but also as important agents of change (Phiri et al, 2022). Women are important stakeholders in agriculture, making up 43% of the labour force in developing countries (Quisumbing et al., 2014). Overcoming gender inequalities in agriculture is key to ensuring global food security (FAO, 2011; Warner et al., 2022). Nevertheless, efforts aimed at strengthening the adaptive capacity of communities, like the development of WCIS, often do not take gender into account (Ngigi & Muange, 2022; Warner et al., 2022). The provision of WCIS is neither efficient nor effective if it doesn't include the preferences and needs of half the population (Gumucio et al., 2010; Phiri et al., 2022; UNDP, 2019). However, there is a lack of gender-disaggregated data (UN, 2019).

For example, in Ghana, in 2020, only 40.1% of the gender data needed to monitor the SDGs from a gender perspective was available (UN Women, n.d.). Ghana, which is part of the Global South, is vulnerable to the impacts of climate change (Nyadzi et al., 2021). With female farmers responsible for approximately 70% of the crop food production in the country (JICA, 2013; Phiri et al., 2022), it is crucial that gender-disaggregated data is collected for agriculture.

1.2 Research Objective

This thesis collects gender-disaggregated data and takes several steps to facilitate the development of a WCIS that provides a hybrid forecast tailored to the needs of both male and female farmers. Firstly, we will research the information needs of male and female farmers, to provide insights into the preferences and knowledge of both genders. Secondly, we will collect local forecast data. It is currently difficult to integrate local forecasts with scientific forecasts due to a lack of long-term local forecast data. Multiple researchers have addressed the need for systematic documentation of indigenous knowledge, including the accuracy of local forecasts (Chang'a et al., 2010; Radeny et al., 2019). Therefore, in this study, we will identify, and document local indicators used by male and female farmers to forecast precipitation and soil moisture. The indicators will be classified into the spatial scale on which they are applied. This gives insight into whether indicators are used and have the same meaning across the world, because an indicator performing in one region may not be present or have a similar performance elsewhere (Gbangou et al., 2021). Furthermore, we will assess the skill of the local forecast created by male and female farmers. Using a gender lens is a perspective that has not been used in the documentation of indigenous knowledge or evaluation of local forecasts so far. Fourthly, and lastly, we will research the perception of farmers towards both local and scientific forecasts and assess whether their perception changes after the farmers have been introduced to a WCIS, the DROP app, that provides scientific and local forecasts. The research focuses specifically on Northern Ghana.

To summarize, this thesis aims to evaluate local and scientific forecasts used in Northern Ghana based on differences between male and female farmers in information needs, indigenous knowledge, forecast skill and forecast perception, to facilitate the development of gender-responsive WCIS.

1.3 Research Questions

To meet the objective of this study, the following main research question has been formulated: *How do male and female farmers in Northern Ghana differ in their information needs, indigenous knowledge, forecast skill and forecast perception?*

The main question will be answered using the following sub-questions:

1. What weather and climate information do male and female farmers in Northern Ghana need?
2. What indicators do male and female farmers in Northern Ghana use to forecast precipitation and soil moisture, and are these indicators applied globally?
3. What is the skill of local precipitation forecasts created by male and female farmers in Northern Ghana, derived from systematic evaluation metrics?
4. How does the perception of indigenous and scientific forecast skills change among male and female farmers from Northern Ghana, after familiarisation by training?

2 Concepts

2.1 Indigenous Knowledge and Local Forecasts

Indigenous knowledge is a concept widely used in (scientific) literature. Different definitions of the concept are used, but the essence is the same: indigenous knowledge is a cumulative and evolving body of knowledge generated within communities through long-term observations of the local environment, weather, and climate patterns (Berkes et al., 2000; Kassa and Temesgen., 2011; Luseno et al., 2003; Mafongoya and Ajayi, 2017; Nyadzi et al., 2021; Radeny et al., 2019; Roncoli et al., 2002; Ziervogel & Opere, 2017). The knowledge is adapted to the local needs and conditions and passed down through generations by oral transmission. Different terms are used interchangeably to refer to indigenous knowledge, including local knowledge, indigenous science, traditional knowledge, traditional ecological knowledge, farmers' knowledge, and rural knowledge (Nyadzi et al., 2021). Weather forecasts based on indigenous knowledge are referred to as local forecasts and are made by local people. The forecasts are based on years of experience and observation of indicators (Nyadzi et al., 2021; Ziervogel & Opere, 2010). Rainfall indicators can be sorted into six categories: *meteorology* (e.g., wind direction), *astronomy* (e.g., the position of the moon), *animals* (e.g., the behaviour of insects), *plants* (e.g., the fruiting of a tree), *multiple* (if the indicator signal is a combination of categories), and *other* (Gbangou et al., 2021; Nyadzi et al., 2021; Radeny et al., 2019; Snoeren, 2020). Snoeren (2020) performed a literature review to document which rainfall indicators are used around the world. Her study found a total number of 1349 indicators, of which the majority (984) were found in Africa.

2.2 Scientific Forecasts

Scientific forecasts are in literature also referred to as modern or conventional forecasts (Gbangou et al., 2021; Plotz et al., 2017). Nowadays, scientific weather forecasts are mainly based on numerical weather prediction (NWP) (Pu & Kalnay, 2018). Many countries have their own NWP systems to generate daily forecasts. With the development of computers, data assimilation and models, and increased availability of satellite data, the skill of NWP has improved progressively over the past decades (Bechtold, 2019; Dias et al., 2018; Pu & Kalnay, 2018). However, despite advancement, the skill of NWP is still distinctly lower for regions near the equator than at higher latitudes. According to Haiden et al. (2012), the NWP skill of forecast day one in the tropics is equal to the NWP skill of forecast day six in the extra-tropics. One reason for that is that tropical variability is more linked to convection and cloud-radiation feedback, which is one of the major uncertainties in current weather and climate predictions (Dias et al., 2018). In Ghana, scientific forecasts are provided by the Ghana Meteorological Agency (GMet). They post the 24-hour forecast for 25 major cities on Facebook each morning. Furthermore, GMet provides a seasonal forecast for the rainy season for the Northern and Southern parts of Ghana.

2.3 DROP App

WCIS are services providing weather and climate information to assist agricultural decision-making, thereby mitigating climate risks (Hewitt et al., 2012; Partey et al., 2020; Warner et al., 2022). An example of such a service is the DROP app: an Android app designed for the needs of smallholder farmers in northern Ghana. It provides scientific 1-, 7- and 14-day rainfall forecasts from meteoblue, a local rainfall forecast based on forecasts submitted by local farmers, and a 7-day soil moisture forecast (Lefèvre, 2022). In the future, the DROP app will also include a hybrid rainfall forecast that is created using a machine-learning approach. Meteoblue is a Switzerland-based company that creates and shares local weather information of high quality (meteoblue, n.d.-a), using weather models based on Nonhydrostatic Meso-Scale Modelling technology (meteoblue, n.d.-b). For some areas of the world, model calculations are performed for so-called *domains*, that comprise (parts of) continents, to give more precise weather information. For example, several domains exist for Europe. Global models provide the boundary conditions for domain forecasts (meteoblue, n.d.-b). However, Ghana is not part of any domain, and therefore the rainfall forecasts are based on the global models NEMS30 and NEMS2-30, which have a spatial resolution of 30 km. To put this in perspective, rainfall forecasts for The Netherlands are based on models with a spatial resolution of 4 km (meteoblue, n.d.-d).

The app has multiple functions:

1. User profile.
2. Share forecast: here farmers share their local rainfall forecast by indicating whether they think it will rain today or tomorrow and the rainfall amount they predict.
3. Share observation: here farmers share their rainfall observations from the past day.
4. View forecast: here farmers can see the scientific 1-, 7 and 14-day rainfall forecast from meteoblue, and the local forecast based on the predictions of peer farmers in the same location.
5. Soil moisture: here farmers can fill in the initial soil moisture condition and see the soil moisture forecast for the coming 7 days.

The development of the DROP app fills an important gap, as it is one of the first WCIS to include soil moisture information. Smallholder farmers in the Global South could greatly benefit from a coupled WCIS-SM as it would help plan decisions, prepare for extreme events, reduce agricultural losses, and thereby provide more income security (Sutanto et al., 2022). The development of the app uses a bottom-up approach, which means that the farmers are included in the production process. Furthermore, the app allows farmers to share their own forecasts. For these reasons, the farmers are more likely to trust and use the service, as it is tailored to their needs and includes their local knowledge (Gbangou et al., 2021; Nyadzi et al., 2022; Paparrizos et al., 2022; Radeny et al., 2019; Sutanto et al., 2022).

For this thesis, the DROP app is used as a tool to retrieve rainfall observation data and local forecast data, and to investigate farmers' perception of scientific forecasts.

2.4 Agricultural Decision-Making

This thesis focuses on analysing knowledge and forecasts used by farmers in agricultural decision-making. Farmers must make numerous decisions throughout the year. These decisions can be categorized into pre-season (e.g., choosing crop variety), in-season (e.g., fertilizer application), end-season (harvest date), and out-season (e.g., yield storage) decisions, based on when the decision takes place (Van der Burgt et al., 2018). Another way to categorize agricultural decisions is based on the time horizon of the implications. Agricultural decisions are then again divided into 3 categories: operational, tactical, and strategic decisions (Haigh et al., 2015; Kumar et al., 2020). Operational decisions are short-term, day-to-day decisions, like deciding whether to apply fertilizer that day. Tactical decisions are medium-term, for example, deciding on a planting date. Lastly, strategic decisions are long-term decisions, such as the choice of crop type.

The different decision types require different types of information that may or may not always be available (Haigh et al., 2015). For operational decisions, forecasts with a short lead time are useful, while strategic decisions like the selection of crop type need a seasonal forecast (Kumar et al., 2020). Especially for farmers engaged in rainfed agriculture, it is crucial to know the onset and cessation of the rainy season, and the within-season variations in rainfall to decide on when to plant, what to plant and when to harvest (Van der Burgt et al., 2018; Ziervogel & Opere, 2010). Because of the different types of agricultural decisions to be made, it is not only important to research whether scientific and local forecasts give the right prediction but also whether the forecast has the right lead time and is provided at the right moment.

3 Data and Methods

To answer the main research question, a mixed-methods approach is used, analysing both qualitative and quantitative data (Nyadzi et al., 2022; Kumar et al., 2020; Shorten & Smith, 2017). The different methods were applied in two different phases: a data collection phase, of which a substantial part took place during fieldwork in Ghana, and a data analysis phase. In Figure 1, an overview of the data and methods used in this thesis is presented. In the following sections, the study area and methods are discussed in more detail.

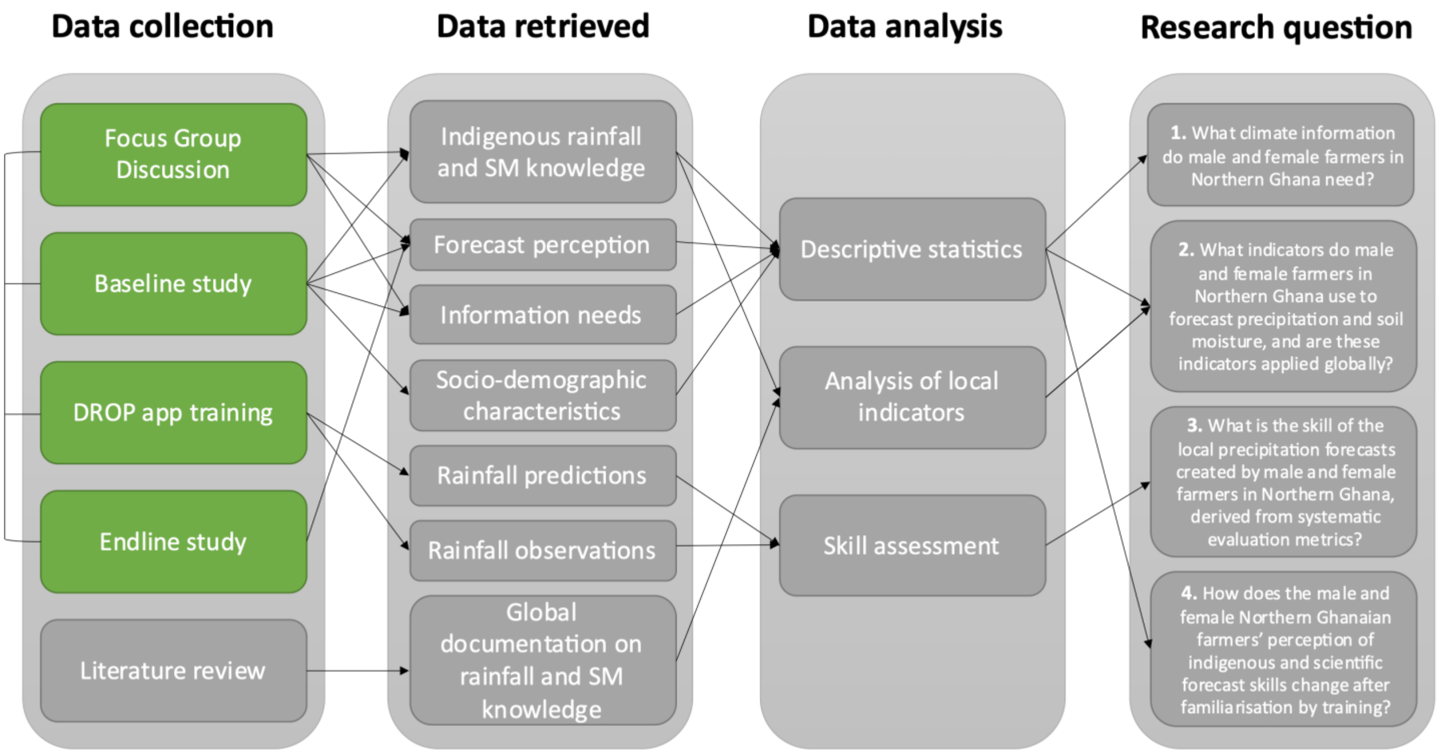

Figure 1 Overview of the data and methods used to answer each research question. SM is used as an abbreviation for soil moisture.

3.1 Study Area

This research focuses on the Northern Region of Ghana, located in Sub-Saharan Africa. Here, climate variability and change are most pronounced in all of Ghana (Nyadzi et al., 2021). Furthermore, the Northern Region is most vulnerable to the impacts of climate change due to its high poverty levels, largely rural population, poor agro-climatic systems and high level of subsistence farmers (Alhassan, Kowurnu & Osei-Asara, 2019). With around half of the workers in Ghana working in agriculture, agriculture is one of the most important sectors in the country. Smallholder farmers engaged in rainfed farming contribute to 80% of the agricultural production in Ghana (Gbangou et al., 2021). Moreover, the sector is a great contributor to the local economy, as it produces about one-quarter of the national GDP (FAO, 2015). Most of the local population of the Northern Region is part of the Mole-Dagbani ethnic group (Nyadzi et al., 2022; GSS, 2010), with 44.7% of the population between the age of 0 and 14 years (UNICEF, 2018). The Northern Region of Ghana is situated in a tropical Guinea Savannah Agro-Ecological zone (Sutanto et al., 2022). There is one rainy season, from May to October. The total annual rainfall is around 1250 mm (Abdul-Rahaman & Owusu-Sekyere, 2017) and the annual mean temperature is around 29 degrees Celsius (GMet, n.d.). For this research, fieldwork was conducted in three communities in the Northern Region: Nabogu (9.74 N, 0.82 W), Gushie (9.81 N, 0.86 W) and Diare (9.87 N, 0.87 W) (Figure 2).

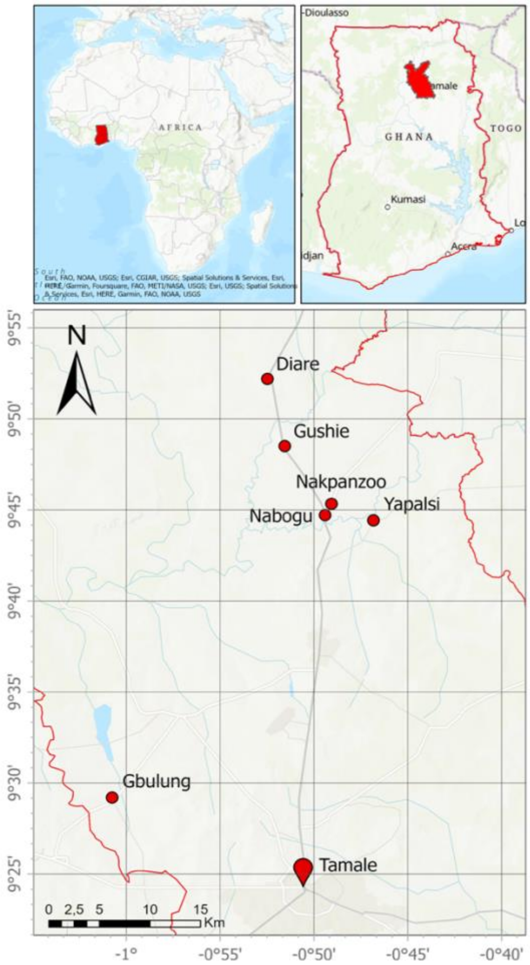

Figure 2 Location of the study area around Tamale, Ghana. Source: Marin Schadee (unpublished).

3.2 Data Collection

As depicted in Figure 1, the data collection phase comprised fieldwork and a literature review. The fieldwork in Nabogu, Gushie and Diare was conducted from September - October 2022. I was accompanied by two students from MAQ, and most fieldwork activities were done together. During the fieldwork, we were assisted by staff and a student from the University for Development Studies (UDS). Before the start of the fieldwork, we were introduced to the chief of each community to ask for approval to do our fieldwork in their community. After approval, one key informant also referred to as the farmer leader, was determined for each community that helped us to contact participants for our study. Ten male and 10 female farmers participated in each community to have a gender balance, resulting in a total of 60 participants. As most community members speak little or no English, the UDS student, who speaks Dagbani, accompanied us to translate for us. Furthermore, we got assistance from two educated community members from Nabogu and Gushie who provided additional help in translating. We started the fieldwork in Nabogu, followed by Gushie and lastly Diare. Additionally, we continued the collection of local forecast data in Yapalsi, Nakpanzoo and Gbulung (Figure 2), which was started by Lefèvre (2022) in June. An overview of the exact timeline of fieldwork is presented in Appendix III (Figure A.III - 1 and Figure A.III - 2). A full fieldwork report is provided in

Appendix IX – Fieldwork Report. In this Chapter, the data collection methods are described.

3.2.1 Focus Group Discussion (FGD)

In each community we held two focus group discussions (FGDs); one with five male participants and one with five female participants. The goal of the FGDs was to get a general idea of the opinions of the local farmers regarding weather information and forecasts and to cross-validate the answers given in the semi-structured questionnaires that will be discussed in the following section (Van Eeuwijk and Angehrn, 2017). The leading questions used during the FGDs are shown in Appendix VII.A – FGD Leading Questions. Due to socially constructed gender norms, men generally have the decision-making power, and thus social interaction between the genders can remain limited (Gumucio et al., 2019; Henriksson et al., 2021). Because women might therefore not feel free to voice their (honest) opinions in the presence of men, the genders were separated during the discussions.

3.2.2 Semi-Structured Questionnaires

During the fieldwork, we conducted two separate semi-structured questionnaires: one for a baseline study, and one for an endline study. Semi-structured questionnaires were used because they allow for including questions that are not predefined (Adams, 2015). We used KoboToolbox software to create the questionnaires (https://www.kobotoolbox.org/). The questionnaires were conducted as interviews using KoboCollect, which is an Android app that allows for collecting data offline. The data was submitted to the KoboToolbox server at a time and location where a stable internet connection was present. The complete questionnaires of the baseline and endline study are provided in Appendix I – Baseline Study Questionnaire and Appendix II – Endline Study Questionnaire, respectively.

The baseline study was performed after the completion of the FGDs. Conducting a baseline study was necessary since this study was the first time that we collaborated with the three communities. The baseline study serves to retrieve socio-demographic characteristics of the participants, which might provide useful insights into what causes differences between the knowledge, needs, and perceptions of men and women. Furthermore, the baseline study is used to research the agricultural information needs of the farmers and the initial perception of farmers towards scientific and local forecasts. Additionally, the indigenous knowledge of local indicators was documented in the baseline study.

The endline study was performed in the final phase of the fieldwork, toward the end of the rainy season. The endline study serves to research whether introducing farmers to the DROP app has led to changes in their perception of scientific and local forecasts. It is important to consider farmers' perceptions towards local and scientific forecasts. As an information provider, one might be under the impression that a product is very valuable to users, but if the users do not agree, do not trust, or do not understand it, the app is not useful (Sarku et al., 2022; Sutanto et al., 2022). Because of time constraints, the endline study could not be conducted with all the farmers that participated in the baseline study. As the farmers in Nabogu had been introduced to the DROP app first, we conducted the endline study in this community. Moreover, one male farmer from Gushie participated. However, due to an error, not all KoboCollect submissions were saved. Therefore, we only have data from 14 participants: seven female participants from Nabogu, six male participants from Nabogu and one male participant from Gushie. With seven male and female participants, the endline study has a gender balance.

3.2.3 DROP App Training

After the baseline study questionnaire, farmers were introduced to the DROP app during training sessions. As the training had to be in the local language Dagbani, the UDS student took the lead during these sessions. By introducing the farmers to the DROP app while it was/is still under construction, farmers are involved in the co-production of the hybrid forecast. This allows them to both better understand the forecast and enhance their trust in it (Paparrizos, 2022).

We taught farmers how to use the DROP app; how to interpret the scientific forecasts with different lead times and probabilities, to enter their local rainfall forecast, and to see the local forecasts submitted by other farmers in the community. Moreover, farmers were taught to enter their rainfall observations in the app. We brought rain gauges to each of the three communities for in situ rainfall observations and taught the farmers how to read them. We asked a few literate farmers to read the rain gauges every day and to enter the observed rainfall in the DROP app. The other farmers entered their observations based on their perceptions.

Furthermore, after training, the participating farmers were asked to use the DROP app daily. For daily use, farmers had to share the devices provided by the project. Each morning before 9 o'clock, farmers could fill in their rainfall forecast for today and tomorrow in the DROP app under "Share Forecast", by indicating whether they think it will rain or not (Lefèvre, 2022). For many meteorological events, such as rain and floods, predictions are regarded as binary events. The forecasts are therefore often statements saying whether the meteorological event will or will not happen (Nyadzi et al., 2021). These forecasts are referred to as yes/no forecasts. The collection of farmers' yes/no rainfall forecasts resulted in a dataset with local forecast data. Furthermore, farmers were asked to submit their rainfall observations every day under "Share observation", which in the end resulted in a dataset with locally observed rainfall data. However, due to several delays, the yes/no rain dataset of the three communities is very small because the farmers were only introduced to the DROP app near the end of the rainy season. Therefore, in this research, the data collected by Lefèvre (2022) will be used. In her study, farmers of the communities Nakpanzoo, Yapalsi and Gbulung (Figure 2) were trained to use the DROP app in the period from June – August. During our fieldwork, we continued the data collection in these communities. As Nakpanzoo and Yapalsi are situated very close to the three communities researched in this study and because we have a longer dataset of local forecasts and observations from these two communities, we will use this data instead.

3.2.4 Systematic Literature Review

To assess whether the rainfall and soil moisture indicators used by the farmers in this study are local, regional or global, a systematic literature review was performed. Snoeren (2020) performed an extensive literature search to document local rainfall indicators used around the world. In this thesis, this documentation was updated by a new literature review of articles published after 2019. Together, these documentations are used to investigate whether the rainfall indicators used in Northern Ghana are applicable globally. As no extensive documentation exists of indicators that are used for forecasting and monitoring soil moisture, a systematic literature review on soil moisture indicators was also performed.

For the literature review, the databases Scopus and Web of Science were used, which are two major databases of peer-reviewed literature (Harzing and Alakangas, 2016). Using multiple databases helps to cover most of the published articles on the topic, and thereby gives the most accurate results (Tawfik et al., 2019). To perform the literature review, several steps were taken: forming search criteria, creating a search strategy, searching the databases, title and abstract screening for eligibility, full-text screening, and finally extracting the data and analysing its quality (Tawfik et al., 2019). Before the titles and abstracts were screened, duplicates were removed in Excel. The actual search was performed on February 1st, 2023. The search queries for the rainfall and soil moisture are shown in Table 1 and Table 2, respectively. As the literature review on rainfall was supposed to complement the documentation by Snoeren (2020), the same search query was used, but only articles published after 2019 were included. A schematic overview of the steps taken in the literature reviews on rainfall and soil moisture indicators is included in Appendix IV – Systematic Literature Review (Figure A.IV - 1 and Figure A.IV - 2).

Table 1 Overview of the search queries per database for the systematic literature review on rainfall indicators.

Database	Search query	Number of articles
Scopus	(ALL (("local knowledge" AND forecast AND agriculture)) OR ALL (("traditional knowledge" AND forecast AND agriculture)) OR ALL (("indigenous knowledge" AND forecast AND agriculture)) OR ALL (("local forecast knowledge" AND forecast AND agriculture)) OR ALL (("traditional forecast knowledge" AND forecast AND agriculture)) OR ALL (("local forecast knowledge" AND forecast AND agriculture))) AND PUBYEAR > 2019 AND (LIMIT-TO (LANGUAGE , "English"))	482
Scopus	(TITLE-ABS-KEY (tradition OR traditional OR traditionally OR indigenous OR local OR locally) AND TITLE-ABS-KEY (forecast OR forecasting OR prediction OR predicting OR predict) AND TITLE-ABS-KEY (weather OR climate) AND TITLE-ABS-KEY (agriculture OR agricultural OR farming OR farmer OR husbandry OR pastoralist OR herder OR smallholder OR cultivation OR tillage OR crops)) AND PUBYEAR > 2019 AND (LIMIT-TO (LANGUAGE , "English"))	871
Scopus	TITLE-ABS-KEY (("forecasting" OR "forecast" AND "local farmers" AND weather)) AND PUBYEAR > 2019 (LIMIT-TO (LANGUAGE , "English"))	6
Web of Science	(TS=(tradition OR traditional OR traditionally OR indigenous OR local OR locally) AND TS=(forecast OR forecasting OR prediction OR predicting OR predict) AND TS=(weather OR climate) AND TS=(agriculture OR agricultural OR farming OR farmer OR husbandry OR pastoralist OR herder OR smallholder OR cultivation OR tillage OR crops)) Refined by: Languages: English Timespan: 01/01/2020 – 01/02/2023	924

Table 2 Overview of the search queries per database for the systematic literature review on soil moisture indicators.

Database	Search query	Number of articles
Scopus	(TITLE-ABS-KEY ("soil moisture" OR ("water holding" AND soil) OR ("moisture holding" AND soil) OR ("water content" AND soil) OR "soil wetness") AND TITLE-ABS-KEY (monitor* OR predict* OR forecast* OR knowledge OR indicator) AND TITLE-ABS-KEY ("small-scale farm*" OR "subsistence farm*" OR "smallholder farm*" OR smallholder* OR farmer* OR agricultur* OR husbandry OR pastoralis* OR herder OR cultivat* OR tillage OR crop*) AND TITLE-ABS KEY (tradition* OR indigenous OR "local knowledge" OR "local indicator*")) AND (LIMIT-TO (LANGUAGE , "English"))	638
Web of Science	(TS=("soil moisture" OR ("water holding" AND soil) OR ("moisture holding" AND soil) OR (“water content” AND soil) OR "soil wetness") AND TS=(monitor* OR predict* OR forecast* OR knowledge OR indicator*) AND TS=("small-scale farm*" OR "subsistence farm*" OR "smallholder farm*" OR smallholder* OR farmer* OR agricultur* OR husbandry OR pastoralis* OR herder OR cultivat* OR tillage OR crop*) AND TS=(tradition* OR indigenous OR "local knowledge" OR "local indicator*")) Refined by: Languages: English	421

3.3 Data Analysis

After return from the fieldwork and completion of the literature review, the data was analysed. In the following sections, the methods for data analysis are discussed.

3.3.1 Descriptive Analysis

The data from the FGDs, semi-structured questionnaires, and general fieldwork notes were first sorted and cleaned. The questionnaire data, both from the baseline and endline study, was transferred to Excel, and the notes from the FGDs and other notes were transferred to Word. Subsequently, the questionnaire data was analysed in Excel with simple descriptive statistics to summarize the data into percentages for each gender.

3.3.2 Analysis of Local Indicators

After all the articles on rainfall indicators were reviewed, the indicators that were found in the search were classified into the indicator categories: *animals*, *astronomy*, *meteorology*, *plants*, *multiple* and *other*. The category *multiple* is used when the indicator's signal is a combination of multiple categories. An indicator is classified into the *other* category when it does not match any of the other defined categories. In the categories *animals*, *astronomy*, *meteorology* and *plants*, sub-categories were created. For example, the category *animals* is divided into *amphibians*, *birds* and *mammals*, amongst others. This classification approach is based on the research of Snoeren (2020), Gbangou et al. (2021), Nyadzi et al. (2021) and Radeny et al. (2019). All indicators including their category, region and source were transferred to Excel to create a table. Furthermore, this new documentation and the documentation by Snoeren (2020) were used to classify the indicators found during the baseline study into spatial scales on which they are applied. If an indicator is specific to one place, it is classified as local. If the signal and the predicted outcome of an indicator correspond with an indicator in another Sub-Saharan country or another continent, the indicator was classified as regional or global, respectively. For example, if indicator A is found in both Ghana and Senegal, it was classified as regional. The soil moisture indicators were not categorized into spatial scales. Instead, they are classified into indicators used for monitoring and prediction. This is argued in Chapter 4.4.

3.3.3 Skill Assessment

To assess the performance of the local forecast created by male and female farmers, the rainfall predictions and observations are compared using categorical statistics. There are several common metrics to assess the skill of a forecast, such as accuracy, Hanssen-Kuipers (HK), probability of detection (POD), and false-alarm ratio (FAR) (Paparrizos et al., 2022; Gbangou et al., 2021). For this thesis, these metrics are used to provide insight into the performance of local forecasts and to compare the female and male forecasts. Table 3 shows the contingency table that is used to calculate the accuracy, HK, POD and FAR skill scores.

Table 3 The possible combinations of observed and forecasted rainfall events (Woodcock, 1976).

Event observed	**Event forecasted**	
	Yes	No
Yes	A: Hit	B: Miss
No	C: False alarm	D: Correct negative

The accuracy of the forecast is the fraction of correct forecasts, and it can range from 0 to 1. An accuracy of 0 means that the forecast is always incorrect, whereas a score of 1 means that the forecast is always correct. The accuracy is calculated as follows:

$$Accuracy = \frac{A+D}{A+B+C+D} \quad \text{(eq. 1)}$$

The HK discriminant is used because it is "universally acceptable for evaluating yes/no forecasts for scientific purposes", according to Woodcock (1976). The discriminant is furthermore used in multiple publications on local and scientific forecasts, including Paparrizos et al. (2020) and Gbangou et al. (2021). The HK indicates how well a forecast can distinguish between rain and no rain events (Woodcock, 1976). The HK score can range from -1 to 1. The closer the score is to 1, the better the forecast can discriminate between 'yes rain' and 'no rain'. A score of ≤ 0 indicates no skill, with a score of -1 indicating that the forecast is always wrong. A skill of 1 indicates a perfect score (Gbangou et al., 2021). To calculate the HK skill score, the following Equation is used:

$$HK = \frac{AD-BC}{(A+B)(C+D)} \quad \text{(eq. 2)}$$

While the accuracy and HK skill score are useful in evaluating the performance of the local forecasts, it is good to complement them with other metrics, like the FAR and POD, to provide additional information about the forecast performance. By using a combination of metrics, we can better understand the strengths and weaknesses of the forecast. The POD score gives the fraction of the observed rain events that were correctly forecasted (hits), as can be seen from Equation 3 (WMO, 2015). The POD skill score can range from 0 to 1, with a score of 1 indicating a perfect score. The POD should always be used in combination with the FAR, as it ignores the number of false alarms. The FAR score gives the fraction of the predicted yes events that were not observed (false alarms), as shown in Equation 4 (WMO, 2015). The FAR score also ranges from 0 to 1, with a skill score of 0 being the perfect score, contrary to the POD.

$$POD = \frac{A}{A+B} \qquad \text{(eq. 3)}$$

$$FAR = \frac{C}{A+C} \qquad \text{(eq. 4)}$$

As previously explained, to compare the local forecast skill of male and female farmers, we use a forecast dataset from Nakpanzoo and Yapalsi, as this is a longer dataset than the one retrieved from Nabogu, Gushie and Diare. The dataset from Nakpanzoo and Yapalsi consists of forecasts submitted by 39 farmers, of which 12 are female and 27 are male. It is important to note that we are not completely certain of the identity of the farmers who submitted forecasts, as it is possible that other farmers submitted forecasts on someone else's account.

Before the skill of the local forecasts is calculated, the data had to be transformed as follows:

1. The farmers' predictions and observations were processed into a dichotomous variable, as it is the occurrence of rainfall and not the rainfall intensity that is of interest for this research. A dichotomous (binary) forecast predicts whether it will rain or not ('yes rain' versus 'no rain').
2. Furthermore, duplicates in the datasets had to be removed. If one farmer did multiple forecasts for one day, we removed all except the last prediction done for that day.
3. To remove overlap in the observation dataset, we used a different strategy. In Nakpanzoo and Yapalsi, there was one farmer who entered observations into the DROP app based on the rain gauge. Therefore, we can assume that these observations are accurate. When observations from this farmer were available, we used this observation and removed all other observations from that day. If this was not possible, we considered whether the majority of the other farmers observed rain or not.
4. Moreover, we split the forecasted rainfall dataset into a dataset for male and one for female farmers.
5. Subsequently, the probability of rain (POR) was calculated for each day. The POR is calculated by dividing the number of farmers who forecast rain for a certain day divided by the total number of farmers who submitted a forecast for that same day, and then multiplying this value by 100. If the POR is equal to or higher than 50%, then a value of 1 ('yes rain') would be attributed to the forecast of this day. Otherwise, a 0 was given, indicating that no rain is expected.

Thereafter, the predictions per day are compared to the observations, categorized into hits, misses, false alarms and correct negatives, and the skill metrics of the forecast are calculated.

4 Results

This Chapter provides the results of the baseline and endline study performed during the fieldwork, the literature review and the skill assessment. First, the socio-demographic characteristics of the farmers are presented. The other results are shown in the order of the five research questions.

4.1 Socio-Demographic Characteristics of Farmers

The first section of the baseline study focused on the farmers' characteristics. Analysis of the socio-demographic characteristics of farmers was performed for each community and based on gender. The results per community can be found in Table A.V - 1 (see Appendix V – Baseline Study Results). In this section, the results based on gender, shown in Table 4, will be discussed. Half of the respondents are male; the other half are female. Most participants are in the age group of 30 – 40 years old. More male (30%) than female (10%) farmers over the age of 50 participated. In this study, household size was defined as the number of people under the participant's care. Almost half of the female participants have a household of 6 – 10 members, while most men have a household size of 11 – 15 people or more. The large household sizes reported by the participants correspond with previous research by Biritwum et al. (2013), which showed that household sizes in the Northern Region of Ghana are the biggest in the country with an average of 8.2 persons per household. Nationally, the average is 2 – 5 members (Biritwum et al., 2013).

Table 4 Socio-demographic characteristics of participants.

		Female		Male		Total	
Variable	**Category**	**N**	**%**	**N**	**%**	**N**	**%**
Age (years)	< 30	1	3.33%	4	13.33%	5	8.33%
	30 - 40	15	50.00%	11	36.67%	26	43.33%
	40 - 50	11	36.67%	6	20.00%	17	28.33%
	50 - 60	3	10.00%	4	13.33%	7	11.67%
	> 60		0.00%	5	16.67%	5	8.33%
Household size	1 - 5	6	20.00%	6	20.00%	12	20.00%
	6 - 10	13	43.33%	6	20.00%	19	31.67%
	11 - 15	7	23.33%	8	26.67%	15	25.00%
	16 - 20	2	6.67%	5	16.67%	7	11.67%
	21 - 25	1	3.33%	3	10.00%	4	6.67%
	> 25	1	3.33%	2	6.67%	3	5.00%
Educational level	None	22	73.33%	12	40.00%	34	56.67%
	Non-formal		0.00%	2	6.67%	2	3.33%
	Primary	3	10.00%	5	16.67%	8	13.33%
	Middle/Junior		0.00%	5	16.67%	5	8.33%
	Senior	5	16.67%	3	10.00%	8	13.33%
	Tertiary		0.00%	3	10.00%	3	5.00%
Literacy	No	24	80.00%	15	50.00%	39	65.00%
	Partially	1	3.33%	6	20.00%	7	11.67%
	Yes	5	16.67%	9	30.00%	14	23.33%
Landownership	Yes	8	26.67%	23	76.67%	31	51.67%
	No	22	73.33%	7	23.33%	29	48.33%
Farm experience (years)	1 - 5	8	26.67%		0.00%	8	13.33%
	6 - 10	10	33.33%	2	6.67%	12	20.00%
	11 - 15	2	6.67%	4	13.33%	6	10.00%
	16 - 20	1	3.33%	4	13.33%	5	8.33%
	> 20	9	30.00%	20	66.67%	29	48.33%
Farm size (acres)	1 - 1.9	1	3.33%		0.00%	1	1.67%
	2 - 2.9	2	6.67%		0.00%	2	3.33%
	3 - 3.9	4	13.33%	1	3.33%	5	8.33%
	4 - 4.9	8	26.67%	1	3.33%	9	15.00%
	5 - 6	6	20.00%	4	13.33%	10	16.67%
	> 6	9	30.00%	24	80.00%	33	55.00%

Off-farm income	Yes	20	66.67%	21	70.00%	41	68.33%
	No	10	33.33%	9	30.00%	19	31.67%
Off-farm income compared to farming	Much more			1	3.33%	1	1.67%
	More	1	3.33%	5	16.67%	6	10.00%
	Equal	5	16.67%	2	6.67%	7	11.67%
	Less	11	36.67%	9	30.00%	20	33.33%
	Much less	3	10.00%	4	13.33%	4	11.67%
Farm animals	Yes	8	26.67%	20	66.67%	28	46.67%
	No	22	73.33%	10	33.33%	32	53.33%

Figure 3 shows the educational level of respondents. The educational level ranges from no education to tertiary education (e.g., university). A vast majority of female farmers (73.3%) have not had any schooling, formal, or informal education. On the other hand, more than half of male farmers (53.3%) have formal education. No women have received tertiary education, but three men have. The numbers are comparable to the statistics for the Northern Region, which the three communities are part of. In general, the proportion of adults having received tertiary education in rural areas is three times lower than adults in urban areas (GSS, 2021). Compared to the national average, the Northern Region has the lowest share of rural men (46.8%) and women (27.7%) of 15 years and older who have attended school (GSS, 2019). The low number of women that are educated compared to men might be attributed to the fact that Muslims prefer to educate boy children (Alhassan & Odame, 2015). In the Northern Region, 65.8% of household heads are Muslim (GSS, 2019). While Islam does not dissuade education for girls, Muslim parents prefer to invest in their boy children because girls marry into another household. Another important factor creating inequality in schooling is polygyny, which is accepted and even encouraged in the Northern Region. Due to polygyny, there are large families with multiple wives and many children. To provide enough food for all family members, some children have to remain at home to help at the farm (Alhassan & Odame, 2015). Other factors resulting in gender inequality in education include poverty, fostering, and early marriage.

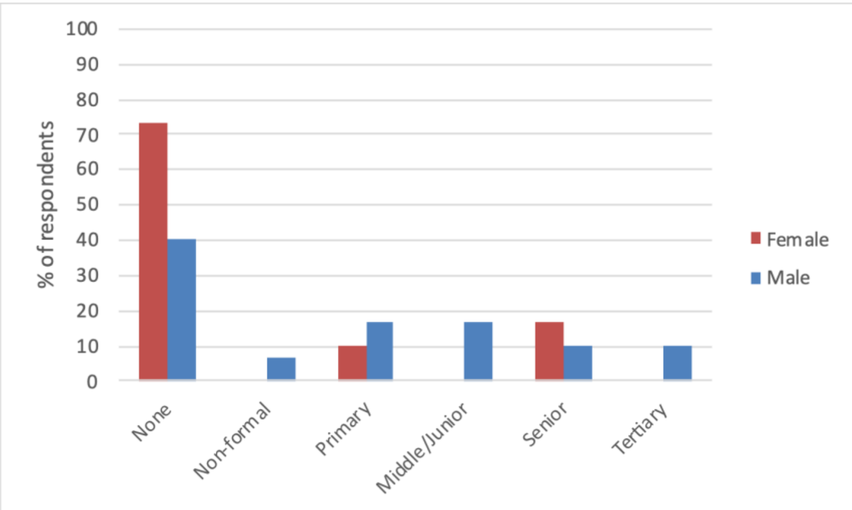

Figure 3 Educational level of respondents.

The results for literacy, as shown in Table 4, seem to largely correspond with the educational level. A large majority of female participants (80%) are illiterate, and only five females are fully literate (16.7%). Of the male participants, half are (partially) literate. This gender pattern resembles findings from a report from the Ghana Statistical Service (GSS, 2021) that showed that only 34.8% of females and 48.1% of males above the age of six living in the Northern Region are literate. Some people who did receive (primary) education answered they are illiterate. By chatting with the participants, we learned that some people are no longer able to read and write because they either did not learn properly in school or forgot over the years because they don't use the skill (Fieldwork note, 2022).

The majority of male farmers (76.7%) were the landowner of the parcel they farm, contrary to the female farmers of whom only a minority (26.7%) owns the farmland, as shown in Figure 4a. In Ghana, both statutory and customary laws on land ownership are recognized by the government. Whereas the statutory laws are in principle not gender-biased, customary laws on land rights usually favour males (Phiri et al., 2022; Yokying & Lambrecht, 2020). In the Northern Region, 73% of farm plots are under customary land tenure systems. One male participant from Diare mentioned that the chief of the community owns all the land and gifts it to farmers, who are then called the 'owners' of the land (Fieldwork note, 2022). According to customary practices, men usually inherit the land, while women only get the right to use the land through their male family members. This seems to be reflected in the farm size of the respondents, as shown in Figure 4b. Male respondents own farm plots larger than female respondents, possibly because women only receive the right to use a small piece of land. Eighty per cent of men have farm plots larger than 6 acres, whereas 70% of women have farm plots less than 6 acres. On average, the women in this study also have fewer years of farming experience than the male participants. This is likely linked to the age of the respondents, as relatively more older men are participating in this study.

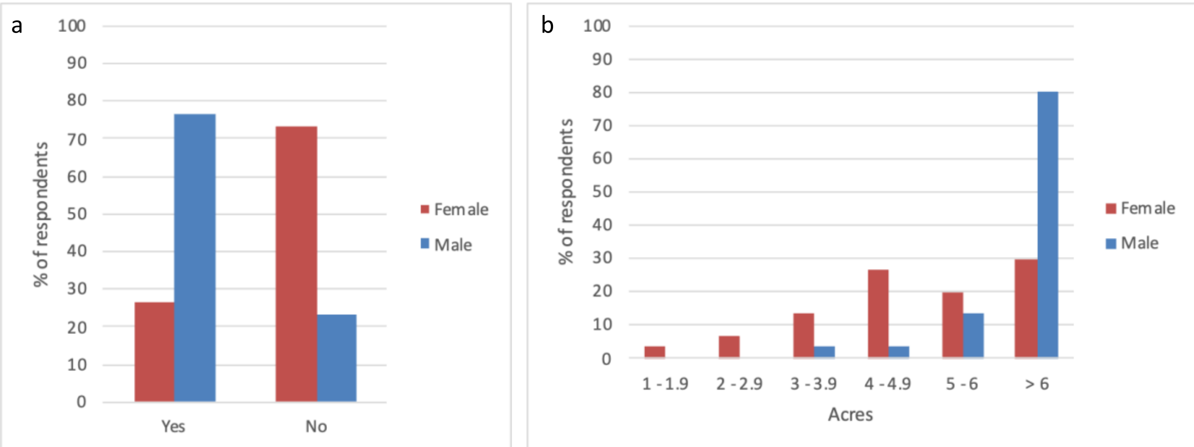

Figure 4 (a) Land ownership of respondents, (b) Farm sizes of respondents.

The majority of farmers (68.3%) reported having off-farm income, with an approximately equal number of male (70%) and female (66.7%) farmers. Most women (46.7%) mention that they receive (much) less income from their other job than from farming. Only one female indicates that she earns more with her side job than with farming. Six males (20%) indicate that they earn (much) more with their side job, while 15 men (50%) indicate that they earn the same or less. Examples of side jobs mentioned by the male farmers are fishing, singing and teaching Arabic. One female farmer indicated that she has off-farm income from trading the food she buys and keeps.

Most participants grow maize, beans (e.g., cowpeas, soybeans), rice and groundnut (Table A.V - 2). More male than female farmers grow maize, rice, beans, and yellow milo (also known as yellow sorghum or yellow millet), but female farmers grow more groundnut and okra than men. Only male respondents reported growing yam, cassava and cabbage. On average, men (4 crop types) grow more different crops than women (3.4 crop types). Besides cultivating crops, some farmers own farm animals. Two-thirds of the participating men have farm animals, while less than one-third of the females have animals for farming.

4.2 Information Needs

This sub-Chapter provides insights into the information needs of male and female smallholder farmers in the Northern Region of Ghana. The first section reports on the agricultural information that farmers are currently receiving, to shed light on preferences regarding and barriers associated with the types and sources of information. The second section shows what climate and weather information the farmers would like to receive to improve their agricultural decision-making.

4.2.1 Information Access

Almost all farmers (98.3%) in the studied communities reported that they receive agricultural information that influences their agricultural decision-making. Only one male respondent claimed that he does not receive any agricultural information because he does not have access. Table 5 shows that weather forecasts are the most obtained type of information for both male and female participants (90% of women, 96.7% of men), followed by crop/variety selection (86.7% of women, 90% of men); input prices and availability (73.3% of women, 80% of men); soil moisture information (76.7% of women, 63.3% of men); disease, pest, and weed control (63.3% of women, 66.7% of men); market prices (63.3% of women, 50% of men); and water availability (36.7% of women, 20% of men). In the category ‘others’, farmers reported receiving training on farm management, fertilizer application, time of planting/sowing, and spacing of crops in the field. There does not seem to be a pattern in the information the two genders received: male farmers receive more information on some categories, while female farmers receive more information on others, but the differences are mostly relatively small.

Table 5 Type of agricultural information obtained by respondents.

		Female		Male	
Variable	**Category**	**N**	**%**	**N**	**%**
Information type	Weather (rainfall) forecasts	27	90.00%	29	96.67%
	Soil moisture	23	76.67%	19	63.33%
	Input prices and availability (fertilizer, pesticides, seeds)	22	73.33%	24	80.00%
	Crop/variety selection	26	86.67%	27	90.00%
	Disease, pest and weed control	19	63.33%	20	66.67%
	Market prices	19	63.33%	15	50.00%
	Water availability	11	36.67%	6	20.00%
	Others	7	23.33%	3	10.00%

The majority of farmers score the quality of each information type category as *good* to *very good* (Figure A.V - 1). Men generally give higher scores than women. Both men and women score weather (rainfall) information most often as *important* to *most important* (90% of women, 93.3% of men), followed by crop/variety selection (83.3% of women, 86.7% of men), soil moisture information (73.3% of women, 70% of men), input prices and availability (70% of women, 73.3% of men), disease control (63.3% of women, 70% of men), and market price (60% of women, 50% of men), as shown in Figure A.V - 2.

Furthermore, participants were asked through which source(s) they receive the information. They could select multiple answers. The results, presented in Figure 5, show that participants receive the information primarily via peer farmers (83.3%), followed by radio (80%) and television (78.3%). An equal number of men and women receive information via peer farmers and radio. Slightly more men receive information through television (83.3% of men vs 73.3% of women). Eighteen per cent of farmers (16.7% of women, 20% of men) receive information through SMS; mostly from MTN (a large mobile network operator in Africa), and few from Vodafone and GMet. Multiple participants reported that they cannot read the SMS they receive and need someone else to read it for them (Fieldwork note, 2022). This is in line with the high level of illiteracy in the communities, as mentioned in sub-

Chapter 4.1. Other sources of agricultural information are NGOs/other formal contacts (33.3% of women, 20% of men), agricultural extension officers (6.7% of women, 13.3% of men), internet (10% of men), and newspapers (3.3% of men). In the category 'other', one female respondent answered that she receives agricultural information from elders, and one male respondent sometimes receives agricultural information through phone calls.

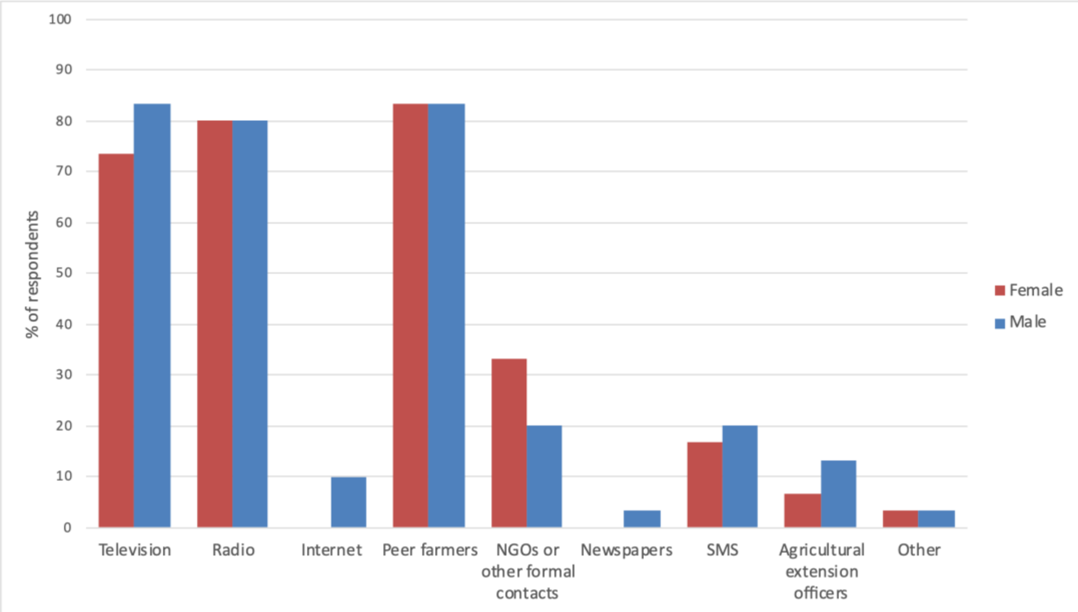

Figure 5 Sources through which respondents receive agricultural information.

Only a few participants receive information via the internet, and they are all male. This might indicate that farmers, especially female ones, have little access to smartphones. This is attested by the study of Partey et al. (2020), which revealed that men have more access to phones than women. According to Gumucio et al. (2020), men more often own communication devices such as mobile phones and radios than women. Men are usually in charge of the household income, and women therefore often lack the resources to buy a phone (Gumocio et al., 2020; Partey et al., 2020). Furthermore, husbands may disapprove that their wives use a phone, and may not find it necessary that their wife has a phone or not have the financial capacity to purchase one for their wife. Another challenge is that women often lack the understanding to use phones due to gender inequalities in education and literacy, as is mentioned in sub-Chapter 4.1 (see Table 4). Both radio and television are communication channels that allow for shared listening to information broadcasts (Gumucio et al., 2020), which likely contributes to the high number of farmers receiving information through these channels in the three communities. However, it is mentioned by one participant that not everybody has access to these appliances, and therefore another way of disseminating information should also be used. The fact that most farmers receive information through peer farmers is not surprising, as peer farmers are easy and free to access. However, one female farmer does mention that she is afraid to ask men for farming information and that she cannot get it from other women (Fieldwork note, 2022). This is in line with what we noticed during our fieldwork; men meet with men, and women with other women, and limited social interactions take place between the genders caused by social norms, as described by Gumucio et al. (2019) and Henriksson et al. (2021).

Furthermore, we asked the farmers what the quality of each information source is. Both genders give television the highest score out of all the information sources (Figure A.V - 3). None of the communication channels is scored as poor or very poor, neither by men nor women. Men give the score 'very good' more often than women, as was also observed for the quality of types of information.

In terms of the frequency of agricultural information, male farmers receive agricultural information more frequently than women, as shown in Figure 6. Seventy per cent of men receive agricultural information *often* or *very often*, versus 40% of women. During the baseline study, one farmer told us that he receives information once a week, which he classifies as *often*. Ten per cent of women and 3.3% of men rarely receive agricultural information, and only 3.3% of men never receive information. The majority of women (50%) receive agricultural information *sometimes*, versus 23.3% of men. The observed gender pattern in the frequency of information corresponds to what mainly female farmers told us during the fieldwork. They do not always have time to listen to information broadcasts, because they are occupied with other (household) tasks. We also noticed this when conducting the baseline study questionnaires, especially in Diare: it was more difficult to conduct the interviews with women because they were preoccupied with tasks like cooking (Fieldwork note, 2022).

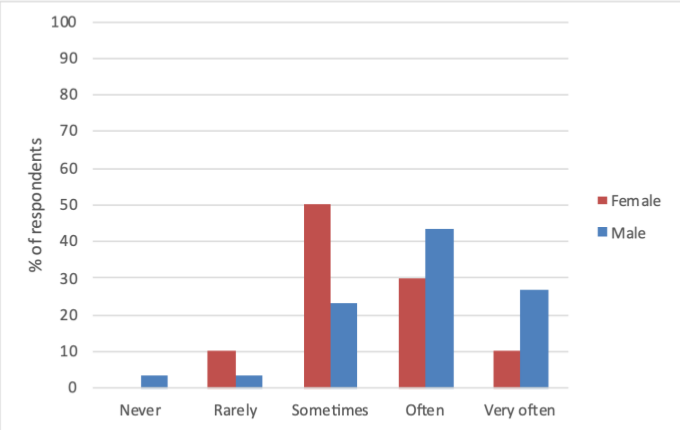

Figure 6 Frequency of agricultural information.

4.2.2 Weather and Climate Information Needs

As this thesis aims to facilitate in the development of a gender-responsive WCIS, one section of the baseline study focused specifically on the forecast information needs of farmers. Farmers were asked whether they agree with the statement: “Weather and climate forecast information is important to make agricultural decisions.” Most farmers strongly agree (56.7% of women, 63.3% of men), as shown Figure 7a. Only one female farmer (3.3%) answered to be *neutral* towards the statement.

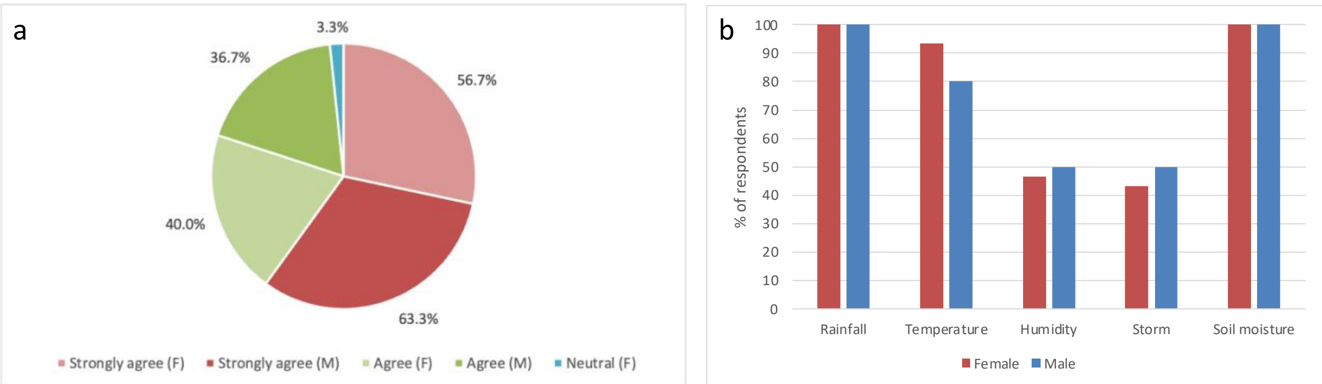

Figure 7 (a) Statement: Do you think that weather and climate information is important to make agricultural decisions? (b) Respondents’ demand for weather and climate information for agricultural decision-making.

All farmers, both male and female, declare that they need rainfall and soil moisture forecast information for agricultural decision-making, as is visible in Figure 7b. This is in accordance with Figure A.V - 4 and Figure A.V - 5, which show that the majority of farmers (male and female) classify both soil moisture and rainfall as *important* to *most important* in all of the agricultural decision-making stages. For temperature, 93.3% of women and 80% of men report that they would like to receive forecasts. Approximately half of the participants would also like to receive humidity and storm forecasts. These findings correspond with the study of Sutanto et al. (2022). When the farmers were asked if there are other types of forecasts they need, one male farmer responded that he would like to receive flood information.

Furthermore, we asked farmers what their preferred lead time of forecasts is. Farmers were allowed to choose multiple options. The results are presented in Figure 8. The most-preferred option for both genders was a 1-week lead time, with 63.3% of female and 73.3% of male farmers that choose this option. In second and third place come a 1-day lead time (53.3% of women, 46.7% of men) and a 3-day lead time (50% of women, 40% of men). The results show that more men are interested in forecasts with longer lead times such as a week, a month, and seasonal (3 months), whereas women are more interested in forecasts with a shorter lead time of 3 days or less. A male farmer indicates that he likes to receive seasonal forecasts to choose the right crops, and monthly forecasts to prepare for his farming activities.

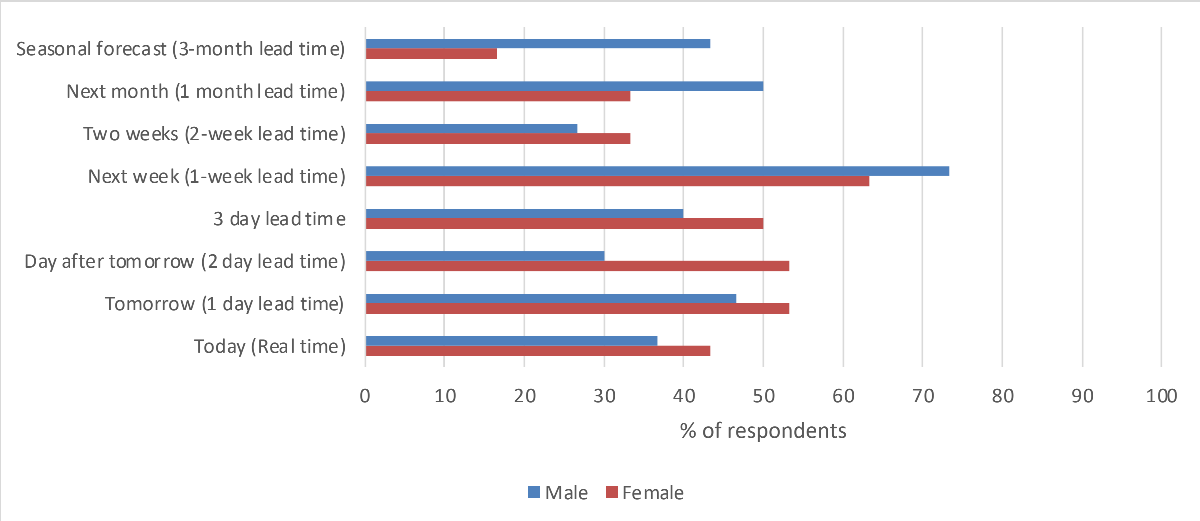

Figure 8 Preferred lead time of forecasts.

4.3 Rainfall Indicators

The number of articles published on indigenous knowledge has rapidly increased since 2006, as shown in Figure A.V - 6. A peak was observed in 2021, with more than 600 articles published on the topic in that year (Malapane et al., 2022). To update and complement the documentation of local indicators for agricultural decision-making that was first created by Snoeren (2020), a literature review was performed on studies published after 2019. Thirty-two articles were included in the documentation. Table 6 shows the number of indicators per continent and category found in this literature review. The majority of studies (19) focus on (Sub-Saharan) Africa, and a few on Asia (8), North America (2), South America (2) and Oceania (2). This division is similar to the results of Snoeren (2020), which also showed that the majority of articles focus on Africa, followed by Asia. Of African countries, Ghana was most frequently the country of focus in this literature review. The indicators found in the included studies belong to the categories: animals (272 indicators), astronomy (47 indicators), meteorology (159 indicators), multiple (1 indicator), plants (126 indicators), and other (41 indicators). Once more, the pattern in the number of indicators in each category corresponds to the research of Snoeren (2020). The documentation of indicators found in the literature review is provided in Appendix X.A - Documentation of Local Rainfall Indicators.

Table 6 Overview of local indicators found, per continent and category.

	Animals	Astronomy	Meteorology	Plants	Multiple	Other	Total indicators per continent
Africa	205	36	130	80		33	484
Asia	37	4	18	16	1	5	81
North America	16	2	6	7		3	34
Oceania	1		1	2			4
South America	13	5	4	21			43
Total number of indicators	272	47	159	126	1	41	646

In the baseline study in the three communities, the local indicators that farmers in Northern Ghana use to predict rainfall were documented. In total, 34 different indicators were reported, as shown in Table 7. The indicators can be categorised into *animals* (12 indicators), *astronomy* (7 indicators), *meteorology* (10 indicators), *multiple* (1 indicator), *other* (2 indicators) and *plants* (2 indicators). The most frequently mentioned rainfall indicators are ants, scorching sun/heat in the body, and wind direction. In general, men know/use more rainfall indicators than women. The average number of rainfall moisture indicators reported by males and females is 3.6 and 2.5, respectively. One female participant indicated that she does not know any rainfall indicators. This is in line with what the female farmers in Diare mentioned during the FGD; that they have less indigenous knowledge than men because they are not close to the men and elderly, and therefore it is difficult to acquire the knowledge.

Table 7 Documentation of local rainfall indicators found in the Northern Region of Ghana.

No.	Indicator name	Signal	Period	Outcome (prediction)	%Farmers	#Female	#Male	#Total	Category	Scale
1	Ants	Ants carrying eggs from hole to hill	Rainy season	The shorter the distance the ants travel, the sooner it will rain. If the distance is within 1 foot: rain today. Within 7 feet: rain in 1 – 2 days or within a week	50%	9	21	30	Animals - Insects	Global: Camacho-Villa et al., 2021
2	Ants	Ants carrying eggs from hill to hole	Rainy season	No rain today	2%		1	1	Animals - Insects	Regional: Ayal et al., 2015
3	Bats nest	When the mouth of the bat nest faces downwards	(Before) rainy season	The rainy season will be relatively wet	2%		1	1	Animals - Mammals	Local
4	Birds (Maliga or saa(chir))	Birds (Maliga or saa(chir)) chirping at daytime (around 3-4 pm). Saachir means 'rain will come' in Dagbani.	Rainy season	Rain within 0 - 1 day	5%		3	3	Animals - Birds	Local
5	Bird eggs	When a bird lay eggs	-	It will not rain for a while	2%		1	1	Animals - Birds	Local
6	Clouds	(Formation of) dark clouds (especially from west to east)	Rainy season	It will rain soon (within ± 3 hours)	15%	6	3	9	Meteorology	Global: Anju & Bonny, 2019

7	Clouds (sound)	When you hear the sound of clouds	Rainy season	Within the time you hear the sound to night/within 3 hours	3.33%		2	2	Meteorology	Local
8	Day	On odd days of the year, you can expect more rain	-	More rain	1.67%		1	1	Other	Local
9	Dew	When you observe no dew in the morning	Rainy season	Rain in 0 - 2 days	8.33%	2	3	5	Meteorology	Regional: Mushimbei & Libanda, 2022
10	Dew (dusk)	No water on the grass in the evening	-	Rain in 3-4 days	1.67%		1	1	Meteorology	Local
11	Duck(s)	Ducks "swimming" on dry soil	Rainy season	Rain within 0 - 2 days	11.67%	4	3	7	Animals - Birds	Regional: Gyampoh et al., 2015
12	Earthworms	When you observe earthworms on dry soil in the daytime (when they come out of their hole/habitat on their own)	Rainy season	Rain within a few hours - 3 days	26.67%	7	9	16	Animals - Worms	Local
13	Fish	Fish playing/fish being active in the river	Rainy season (morning)	Rain within the day	1.67%		1	1	Animals - Fish	Local
14	Fog	When the air is foggy early in the morning or during dusk		Rain in 0 - 2 days	6.67%	4		4	Meteorology	Regional: Nkuba et al., 2020
15	Frogs	Frogs croaking during the day	Rainy season	Rain within 0 - 1 day	13.33%	5	3	8	Animals - Amphibians	Global: Varah & Varah, 2022
16	Frogs + heat	High temperature and frogs croaking	Rainy season	Rain is close	1.67%	1		1	Multiple	Local
17	Moon (halo)	Ring (reddish brown) around the moon.	Rainy season	Rain within 0 - 3 days. The more colour around the moon, the heavier it will rain. The closer the ring is to the moon, the sooner it will rain.	18.33%	1	10	11	Astronomy	Global: Camacho-Villa et al., 2021
18	Moon (halo)	(Dark) ring around the moon during the dry season	Dry season	Rain during the night	1.67%		1	1	Astronomy	Local
19	Insect (Saa paga)	When this insect is flying around the community/field	Rainy season	Rain within the day	1.67%	1		1	Animals - Insects	Local
20	Moon	In the early days (14 days) of the new moon	-	Difficult to predict weather	1.67%		1	1	Astronomy	Local
21	Mosquitos	Intense mosquito bites at night	Rainy season	Rain within 0 - 2 days	11.67%	3	4	7	Animals - Insects	Global: Rivero-Romero et al., 2016
22	Neem tree (Azadirachta indica)	When the neem tree fruits for the second time	Before rainy season	Rain is almost starting	1.67%		1	1	Plants	Local
23	No stars	When you observe no stars at night	Rainy season	Rain within 24 hours	1.67%	1		1	Astronomy	Local
24	No noise	When the environment is completely quiet, no sound of birds or leaves moving	Rainy season	Rain in 1 - 2 days	1.67%	1		1	Other	Local
25	Scorching sun/heat in the	When there is a lot of sun or people	Start and	Rain within 0 – 3 days (One person says if you	65.0%	18	21	39	Meteorology	Regional: Slegers, 2008

	body (+ windless)	feel heat in the body (and there is no wind).	middle of rainy season (not end)	experience it in morning/afternoon: rain at 10 pm. If you experience it in the evening: rain the next day.)						
26	Snails	Snails crawling on trees/leaves (and not on the soil)	Rainy season	Rain within 1 - 2 days	6.67%		4	4	Animals - Other	Local
27	Stars	Stars "swimming" in water (reflection of the stars)	Rainy season	Rain	1.67%		1	1	Astronomy	Local
28	Stars divided	Sky divided by 2 with group of stars on both sides	Rainy season	Rain within 1 - 3 days	1.67%	1		1	Astronomy	Local
29	Sun (halo)	When you see a halo/circle around the sun during the day	Rainy season	Rain that day	3.33%		2	2	Astronomy	Regional: Nyadzi et al., 2021
30	Cotton tree (guaɔ)	When the tree has new leaves	Dry season	Rain is 1 - 2 months away	1.67%		1	1	Plants	Local
31	Wind	Strong wind	Rainy season	Rain within 0 - 2 days	6.67%		4	4	Meteorology	Regional: Mahoo et al., 2015
32	Wind direction	Movement of wind from east to west	-	Varies; from within a few hours - 4 days	28.33%	12	5	17	Meteorology	Global: Shankar et al., 2008
33	Windless (no wind)	When you observe no movement in leaves, no wind	Rainy season	It will rain in a few hours (± 5 hours)	3.33%	1	1	2	Meteorology	Local
34	Yellow cloud	When you observe a yellow cloud in the evening (from 3 - 5)	-	Rain or even storm	1.67%		1	1	Meteorology	Local
Total						**77**	**110**	**187**		

The indicators found in the Northern Region of Ghana were compared to the results of the literature review and the documentation by Snoeren (2020) to classify the indicators into spatial scales on which they are applied. When the signal and outcome prediction of indicators were more or less equal for indicators found in different regions or continents, the indicators are classified as regional or global, respectively. The majority of indicators are applied locally (21 indicators). The others are applied regionally (6) or globally (7). For these indicators, one reference is given in Table 7 to show an example of another area where the indicator is reported. Below, we will discuss the spatial scale of the three most reported indicators by the farmers in the baseline study. For the other indicators found in the three communities, this discussion can be found in Appendix IV – Systematic Literature Review.

Ants as an indicator of rainfall are reported by 50% of respondents (30% of women, 70% of men) in the baseline study. Ants are not only used as an indicator in the Northern Region of Ghana. They are used to forecast rainfall globally, from Vietnam and India (Asia) to Mexico and USA (North America), Bolivia (South America) and multiple countries in Africa (Snoeren, 2020). However, the indicator signal and outcome are not the same everywhere around the world. For example, in eastern Ethiopia, it is believed that the back-and-forth movement of black ants in more than four routes indicates a good season to come (seasonal forecast) (Mekonnen et al., 2021). On the other hand, in Mexico, ants leaving their anthills and taking their eggs to a secure place is an indicator of rain coming soon (short-term forecast) (Camacho-Villa et al., 2021), as it is described by the farmers in the baseline study. Therefore, ants carrying their eggs uphill are classified as a global indicator. The farmers in this research also stated that the distance the ants travel is an important indicator of how soon it will rain, which has not been documented so far.

The feeling of scorching sun and heat in the body, possibly accompanied by windless conditions, is reported as a rainfall indicator by 65% of the respondents (60% of women, 70% of men). This indicator is also reported in the Greater Accra Region of Ghana by Gbangou et al. (2020), and in Tanzania (Slegers, 2008), South Africa (Zuma-Netshiukhwi et al., 2013), and Botswana (Mogotsi et al., 2011). However, in Tanzania, it is reported by Speranza et al. (2010) that sunny and hot weather does not predict rainfall but drought. In the other countries, the outcome is the same as in Northern Ghana. As the indicator is used across Sub-Saharan Africa, it is classified as a regional indicator.

Wind direction as an indicator of rainfall is used by 28.3% of respondents (40% of women, 16.7% of men). This indicator is applied globally, although the wind direction that indicates rain is not the same everywhere. For example, in Andhra Pradesh, wind blowing from the east indicates rainfall (Shankar et al., 2008). Similarly, in the Northern Region of Ghana, a wind blowing from east to west indicates rainfall. This is an indicator that we noticed ourselves during the fieldwork. In the baseline study, some farmers reported this indicator as wind from west to east, instead of east to west. However, since we so clearly noticed that wind from east to west signals rainfall, we document the wind direction indicator as wind from east to west. Another reason for this is that because of the low levels of education and literacy, many farmers are not sure what is 'east' or 'west'.

4.4 Soil Moisture Indicators

During the baseline study, we documented the local soil moisture indicators that the participating farmers use. In total, the participants reported 29 distinct soil moisture indicators, as shown in Table 8. The table shows that male participants are aware of more soil moisture indicators than female participants. The average number of soil moisture indicators reported by males and females is 2.4 and 1.9, respectively. The most frequently mentioned soil moisture indicator is rain (reported 22 times), followed by the deepness of soil moisture (15 times).

We also performed a literature review for soil moisture indicators to create global documentation. Many articles that were found during the search provide indicators for soil quality and use soil moisture as an indicator for quality. Only three articles provided indicators for soil moisture monitoring/prediction. Two of these studies focus on Ghana (Africa), and one on Argentina (South America). The results of the literature review are provided in Appendix X.B – Documentation of Local Soil Moisture Indicators.

Due to the lack of global documentation of soil moisture indicators, the soil moisture indicators are not classified into spatial scales because we cannot properly verify whether the indicators in the Northern Region of Ghana are applied in other areas. Furthermore, due to their character, the local soil moisture indicators found in the Northern Region could in theory all be applied globally, making such classification redundant. Instead, the soil moisture indicators are divided into indicators used for monitoring and indicators used for prediction. Most indicators are used for soil moisture monitoring. Only six indicators could be classified as predictive indicators (Table 8).

Table 8 Documentation of local indicators in the Northern Region of Ghana for monitoring/predicting soil moisture conditions.

No.	Indicator name	Signal	Period	Status/Outcome	%Farmers	#Female	#Male	#Total	Category
1	Cool air from field	When you feel cool air from the field	Rainy season	High soil moisture	1.67%		1	1	Monitoring
2	Current soil moisture	The current level of soil moisture	-	Is an indication of future soil moisture	1.67%		1	1	Prediction
3	Deepness of soil moisture	When you measure the deepness of the soil moisture (e.g., with your hand or a cutlass), and it is deep	Rainy season (ploughing/ planting time)	Soil moisture will last long (high moisture will last 3-4 days to a week)	25%	8	7	15	Prediction

4	Dew	Dew on the leaves/grasses in the morning	-	High soil moisture / good soil moisture	6.67%	1	3	4	Monitoring
5	Dust	When you (use a tractor to) plough and you see a lot of dust/wind can easily blow sand from the soil	-	Low soil moisture	5%	2	1	3	Monitoring
6	Erosion	If the soil erodes after rainfall	-	The soil has low soil moisture	1.67%		1	1	Monitoring
7	Feeling with fingers	Use fingers to feel the soil moisture	-	If you can dip your fingers 7 -9 inches, the soil is moist. If the soil is wet, it will take 4 – 5 days to dry up. Which means the soil is good for sowing.	10%	3	3	6	Monitoring
8	Flowering fruit	If fruits are flowering and they drop their petals	-	No (low) soil moisture	1.67%		1	1	Monitoring
9	Footsteps on the ground	1. When you walk on the soil, and you don't sink into the soil/you don't see footsteps 2. When you do sink into the soil/see footsteps 3. When you sink deep into the ground	Rainy season	1. Soil moisture is low, will not last long 2. Soil moisture is high, will last long 3. Soil moisture is not good for sowing	16.67%	6	4	10	Monitoring
10	Grass	When you see germinating grasses	Start of rainy season	High soil moisture	1.67%	1		1	Monitoring
11	High humidity	-	-	-	3.33%	2		2	-
12	Peer farmers going to farm	If lots of farmers go to their fields	-	Good soil moisture	1.67%		1	1	Monitoring
13	Plant appearance	The body of the crop starts changing (e.g., twisted crop leaves, burned plant hairs)	-	Too low soil moisture	6.67%		3	3	Monitoring
14	Plant appearance	Green looking plants/crops	-	Good soil moisture	1.67%		2	2	Monitoring
15	Rain	Rainfall	Rainy season	When it rains, the soil moisture will increase. The more rain, the longer the soil moisture will last. Otherwise, it will decrease. When the rain is too heavy, the soil moisture becomes too high. Light rain gives the right moisture.	35%	11	11	22	Monitoring
16	River water level	When the water level in the river is increasing	-	Soil moisture is increasing	1.67%		1	1	Monitoring
17	Sand	If you can grab sand from the surface of the soil	-	Low soil moisture	1.67%		1	1	Monitoring
18	(Scorching) sun	Strong sun will reduce the soil moisture	-	Reducing soil moisture/soil moisture will not last long	20%	5	7	12	Prediction
19	Soil aggregates	If the soil has aggregates/if the soil is clumped	Rainy season	High soil moisture (no clumps means low moisture)	1.67%		1	1	Monitoring
20	Soil colour	Moist soil has a different colour.	-	Dark soil is wet, light (could be white) soil is dry	6.67%	1	2	3	Monitoring
21	Soil cracks	Cracks on the soil surface	-	Low soil moisture	3.33%		2	2	Monitoring

22	Soil hardness	1. When you use a hoe or seeding stick, and it is difficult for the tool to enter the soil. 2. When you use a dibber for sowing and loose soil falls into the hole 3. When it is easy to cut into the soil 4. When you use a dibber and soil sticks to the stick	-	1. Low soil moisture 2. Low soil moisture 3. Soil is moist; depending on how hard the soil is, you know how long it will take to dry up. 4. High soil moisture	11.67%	3	4	7	Monitoring
23	Soil type	Soil type will help you determine the moisture level (without rainfall)	-	Some soil types can hold water longer than other types	8.33%	4	2	6	Prediction
24	Strong wind	Strong wind	-	-	1.67%		1	1	-
25	Surface wetness	If the sand/upper part of the surface is dry	-	Low soil moisture, will not last long	3.33%	1	1	2	Monitoring
26	Temperature	High temperature	-	Decrease in soil moisture	15%	6	3	9	Prediction
27	Temperature (soil)	If the soil has a high temperature	-	Low soil moisture	1.67%		1	1	Monitoring
28	Water on the ground	Water puddles on the soil	-	(Too) high soil moisture and will last long	13.33%	3	5	8	Monitoring/ prediction
29	Worms	Worms are an indication of a downpour	-	High soil moisture	3.33%		2	2	Monitoring
Total						**57**	**72**	**129**	

4.5 Skill Assessment

In Figure 9, the results of the skill assessment are presented. It shows the accuracy, HK score, FAR score, and POD score for the local forecasts submitted by male and female farmers in the communities of Nakpanzoo and Yapalsi. From the accuracy, it is immediately visible that the local forecast made by male farmers is better in predicting rain/no rain than the female local forecast. The male forecast is accurate almost 60% of the time (accuracy = 0.58), whereas the female forecast is accurate less than 50% of the time (accuracy = 0.44).

For the HK score, again we see a clear difference between male and female farmers. The HK score can range from -1 to 1, where a value of ≤ 0 indicates that the forecast has no skill. The female HK score of -0.11, therefore, indicates that the female local forecast has no skill. The male forecast has a HK score of 0.08. Whereas this is above 0, it is still very low.

Furthermore, we looked at the FAR and POD skill scores. The POD score of male farmers is 0.92, which indicates that men are very good at detecting rainfall. For female farmers, the POD is 0.78, which also shows that the women are good at detecting approaching rainfall. However, when we look at the FAR, we see that female farmers score a 0.53. This means that rain was forecasted but not observed for more than half of the days. For male farmers, the FAR score is 0.43, indicating that they forecast fewer false alarms. The FAR values obtained from male and female farmers show that both men and women are prone to over forecast rainfall.

These skill scores show that male farmers perform slightly better than female farmers. However, the scores also indicate that neither of the genders is able to properly forecast rainfall and drought, with farmers tending to over forecast rainfall. The fact that men seem to be better at forecasting rainfall, might have to do that they possess more indigenous knowledge. However, it is also important to consider that there were more men who did forecast submissions, and there is a higher number of total forecasts for men and a longer dataset (as shown in Table A.V - 3). The skill score of the women is highly influenced by one female farmer who did 26 submissions. This is likely to also influence the outcome of the skill scores.

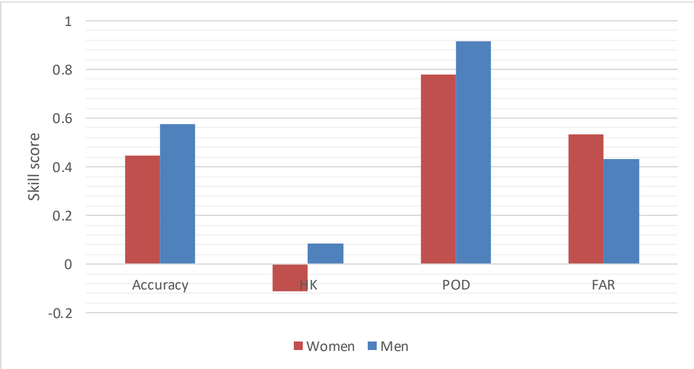

Figure 9 Skill scores: accuracy, HK, POD and FAR, for female and male respondents.

4.6 Farmers' Perception of Forecasts

This sub-Chapter gives insight into the perception farmers have of local and scientific forecasts. In the first sub-section, the initial perception is discussed. The second sub-section shows the perception during the endline study. The endline study was performed towards the end of the rainy season to give insight into the use of the DROP app and to assess whether farmers' perceptions of forecasts have changed after introduction to the forecasts of the DROP app. Important to note is that only 14 farmers participated in the endline study. Therefore, the results might not be representative of the total group of participants of the baseline study. If comparisons are made between the baseline and endline study, this is only done for the 14 participants of the endline.

4.6.1 Baseline Perception

Figure 10 shows how often the respondents use local and scientific forecasts. Fifty per cent of the female participants claim they always use local forecasts for decision-making, 13.3% use it often, 26.7% use it sometimes and 10% use it rarely. On the other hand, only 13.3% always use a scientific forecast. The majority, 40% of the female farmers, use scientific forecasts very often, and 36.7% use them sometimes. Two female farmers (6.7%) never use a scientific forecast. When looking at the men, we see that 40% of the male participants always use local forecasting, 36.7% use it very often, 20% use it sometimes and 3.3% use it rarely. For the scientific forecast, 36.7% of men always use this, 33.3% use it very often, and 26.7% use it sometimes. Only one male farmer (3.3%) never uses a scientific forecast. The results show that more men and women *always* use the local forecast than the scientific forecast. Moreover, there are more men that either use the indigenous or scientific forecast frequently (*very often* to *always*) than there are women who do so.

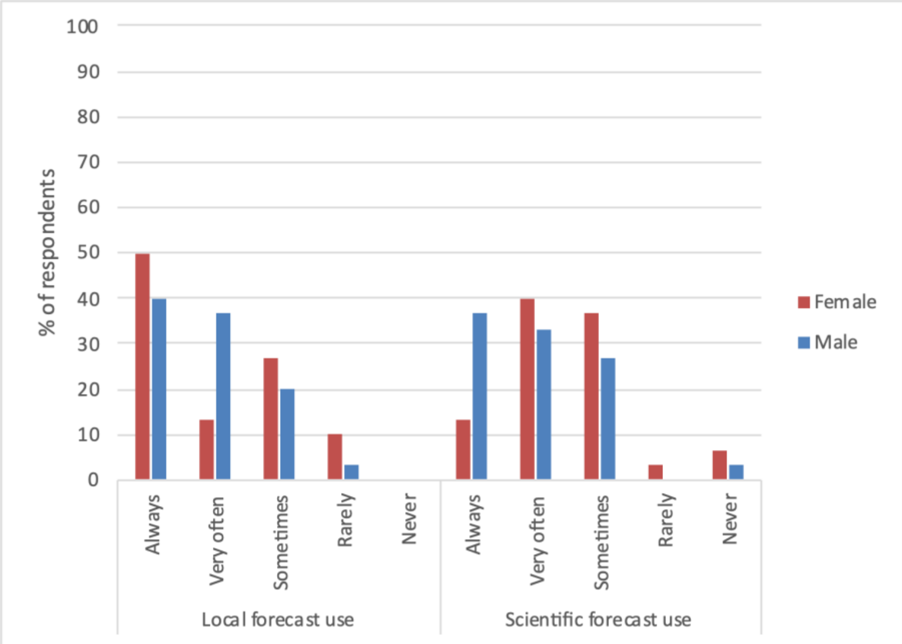

Figure 10 Use of local and scientific forecasts by respondents.

Farmers using local forecasts indicate that they all make them themselves (Figure A.V - 7). Additionally, three male and three female farmers also use local forecasts made by a rainmaker. Rainmakers are usually elders who are believed to not only be capable of forecasting rainfall but also of making it rain (Gumo, 2017). A minority of farmers also use local forecasts made by peer farmers, (grand)parents or elderly. The majority of men and women learned to make local forecasts from their fathers (Figure A.V - 8). For men, this is followed by grandfathers and peer farmers. For women, it is followed by mothers, grandfathers and other relatives equally. Men (grandfathers and fathers) seem to mostly transfer information to male family members and women (grandmothers and mothers) mostly to female family members.

Farmers were asked whether they prefer to use local forecasting over using scientific forecasts. Sixty-three per cent of female and 73.3% of male farmers (strongly) disagree, indicating that they have no preference for the local forecast. Less than a quarter of men (13.3%) and women (23.3%) (strongly) prefer to use the local forecast (Figure A.V - 9).

Furthermore, we asked the farmers about the accuracy of both types of forecasts, and whether the forecasts are often aligned. In general, the results show that farmers are quite positive about the accuracy of both forecast types (Figure 11). The indigenous and scientific forecasts only receive the score poor respectively two and one times. For both forecasts, two female farmers indicate that they do not know the accuracy. This is likely due to a lack of indigenous knowledge and access to scientific forecasts. The farmers score the scientific forecast better than the local forecast: 41 farmers answer that the scientific forecast is accurate to very accurate (60% of women, 76.67% of men), whereas 21 farmers (26.67% of women, 43.33% of men) answer that the local forecast is accurate to very accurate. When the farmers were asked about the accuracy of the forecast during the FGDs, they responded differently. The females of Diare gave the local forecast an accuracy of 10%. An accuracy of 10% does not count as acceptable, and therefore we would expect more females to score the local forecast as poor or very poor. The women in Nabogu and Diare gave the scientific forecast an accuracy of 30 – 45% and 30%, respectively. Again, 30% accuracy does not seem acceptable. While the findings from the baseline study and FGDs do not completely align with each other, it is important to highlight that during the FGDs we noticed that some participants found it difficult to give accuracy a value. This could have resulted in discrepancies between both results. What does correspond in both results is that men give the scientific forecast higher scores than women do, perhaps because they have more access to it or have more knowledge.

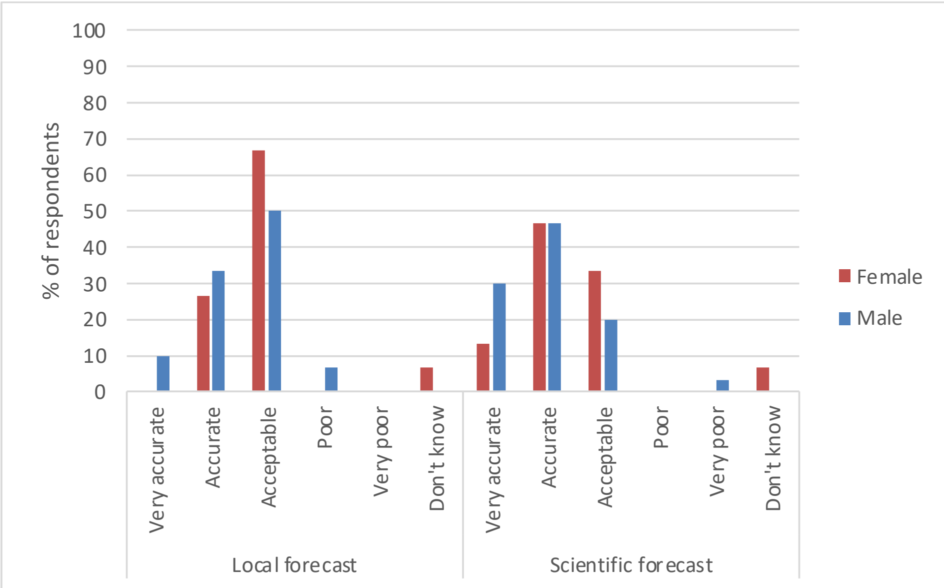

Figure 11 The accuracy of the local and scientific forecast as perceived by the respondents.

When asked about the integration of forecasts, most farmers (93.3% of women, 96.7% of men) claim to already use integrated forecasts, and 43.3% of women and 63.3% of men even use it often to always (Figure A.V - 10). The majority of women integrate the forecasts by combining both, whereas the majority of men compare both forecasts and choose one based on their own experience (Figure A.V - 11). The majority of farmers report that the forecasts are *sometimes* aligned (Figure A.V - 12). A large majority of female (100%) and male farmers (90%) would prefer to receive integrated forecasts (Figure A.V - 13). A major reason for this is that it combines the best of local and scientific forecasts (Figure A.V - 14).

Lastly, farmers were asked about the (dis)advantages of local and scientific forecasts during the baseline study. This means that in the answers, farmers do not consider the advantages and disadvantages of the DROP app, as they were only introduced to the app after the baseline study. An overview of the replies is presented in Table 9. Advantages of the local forecast include that it is accessible and always available, and that it helps with farming activities. The disadvantages mentioned are that it does not give the timing of rainfall and that indicators are not always available. The advantages of the scientific forecast partially overlap with the advantages of the local forecast, but also include that it gives the timing of rainfall and that it gives longer forecasts. One-third of female farmers answered that there are disadvantages to scientific forecasts, versus two-thirds of men. Disadvantages that were mentioned are unreliability of the forecast, that it is not location-specific, accessibility issues, and that they can only receive it when there is electricity.

Table 9 Advantages and disadvantages of local and scientific forecasts (baseline perception).

	Local forecast	Scientific forecast
Advantages	Helps with farming activities	Helps with farming activities
	No costs	Saves resources (time, cost)
	More accessible	Gives timing of rainfall
	Complements the scientific forecast	More accurate
	“It does not fail me”	Can be received directly from the source
	Helps with drying farm produce	Helps with drying farm produce
	Helps with household work	Helps with household work
	Prevents loss of farm produce	Prevents loss of farm produce

	Sometimes works better than SF	Gives longer forecasts
Disadvantages	It does not give the timing of rainfall	You cannot receive it if there's no electricity
	The indicators are not always available	Sometimes you do not have time to listen/watch the forecast
	Low accuracy leading to waste of resources	Accuracy not always high
	Not all farmers have someone to teach them how to use it	Forecast is not timely
	It cannot predict far in advance	Not location specific
	Due to climate change, it works less well	Not always access to the information
		Only broadcasted once a week

4.6.2 Endline Perception

DROP App Usage

At the time of the endline study, all 14 participants responded that they are still receiving forecasts. One female farmer responded to receiving the forecasts through someone else who told her about the information provided by the DROP app, all the other participants accessed the DROP app themselves via a smartphone provided by the project or on their own phone. Furthermore, farmers still check the forecasts. The majority of female farmers (42.9%) check the scientific forecast once a week, while the majority of male farmers (57.1%) check it every other day, as shown in Figure A.VI - 1 in Appendix VI – Endline Study Results. Farmers check the local forecast a little more frequently: most men (42.9%) check it every day, while most women (57.1%) check it every other day (Figure A.VI - 2). Fewer farmers look at the soil moisture forecast: most men (42.9%) never check it, while most women (42.9%) check it every other day (Figure A.VI - 3). The majority of farmers share the rainfall forecasts with peer farmers and approximately half share them with relatives (Figure A.VI - 4).

To give insight into whether the farmers understand the forecasts, farmers were asked about the comprehensibility of the forecasts provided by the DROP app. A majority of respondents report that they find all forecasts easy to understand (Figure 12). Male respondents are more positive about the understandability of the rainfall forecasts, whereas female farmers are more positive about the understandability of the soil moisture forecast. Men find the soil moisture forecast most difficult to understand, with almost 30% reporting it to be very difficult. On the contrary, women find the soil moisture forecast easier to understand.

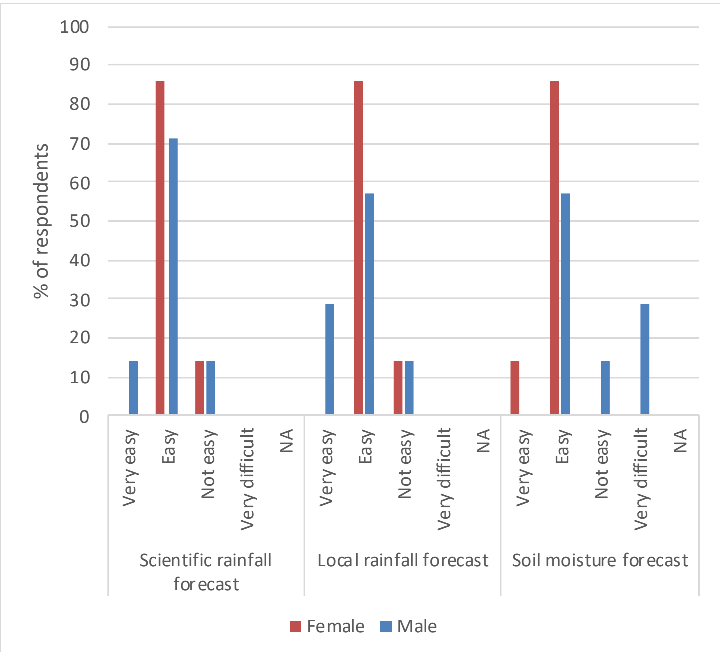

Figure 12 Comprehensibility of the forecasts provided by the DROP app, as perceived by the endline respondents.

Introducing farmers to the DROP app has changed how often the farmers use local forecasts (Figure 13a). During the endline, none of the participants responded that they *always* use the local forecast, while during the baseline farmers did indicate this (57.1% of women, 28.6% of men). This is possibly attributed to the fact that the scientific forecast is now more easily accessible, and farmers are therefore less dependent on the local forecast. However, there are also fewer female farmers who use a local forecast only *rarely* and fewer male farmers who use the forecast only *sometimes*, instead more use it *very often*. This may be caused by people with little indigenous knowledge starting to use the local forecasts based on their peer farmers' submissions.

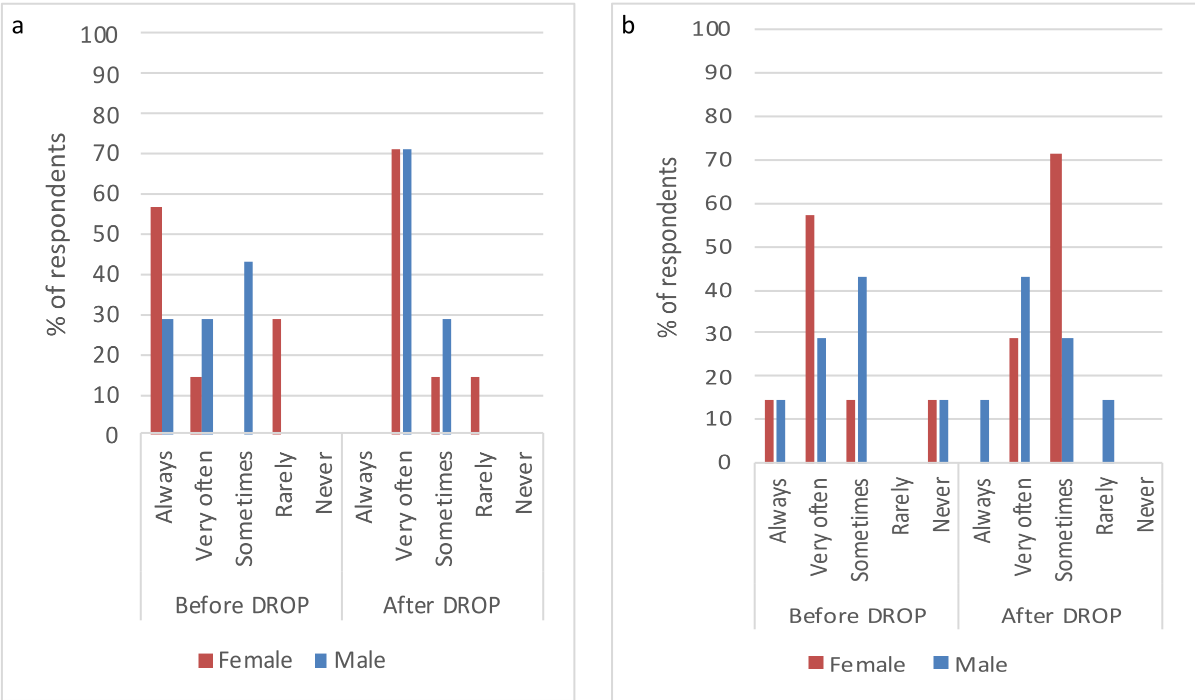

Figure 13 Local forecast (a) and scientific forecast (b) use of endline respondents, before and after DROP app training.

In the endline study, no farmers report that they are *never* using a scientific forecast (Figure 13b). This is likely attributed to the fact that people who previously did not have access to a scientific forecast were able to access it (via the DROP app). Men use scientific forecasts more frequently than women. More male farmers use scientific forecasts *very often* to *always* after the training. On the other hand, more women indicate using a scientific forecast *sometimes* instead of *always* or *very often*, indicating a decrease in frequency. However, when asked directly whether they use the scientific forecast more often after the DROP app introduction, 71.4% of women indicate that they do, and so do all men.

Farmers use the DROP app forecasts for agricultural decision-making. All women use the scientific rainfall forecast, and 71.4% of women use the local rainfall forecast as well (Figure 14). More than 70% of men use the scientific and local rainfall forecast. Only 14.3% of men and women use the soil moisture forecast for agricultural decision-making. Few men (28.6%) claim to not use any of the forecasts for farming decisions. Respondents mainly use the forecast for preparing for daily activities and harvesting. One farmer explained that soybeans are harvested after the rain has stopped. If you have harvested, and then rain falls on the heap of harvested produce, it will spoil. Farmers also used the forecasts for deciding whether to go to their farm or not, to go to the market, whether to dry crops or not, for cooking and to know the moisture content of their farms. One farmer reported that he did not use the forecasts because they had been trained too late. During a field visit to Gbulung, a community that was introduced to the DROP app in an earlier stage, farmers told us that they have used the information for sowing, weeding, fertilizer application, spraying herbicides and harvesting

(Fieldwork note, 2022). All farmers agree that the information has been beneficial to them, also for non-agricultural activities.

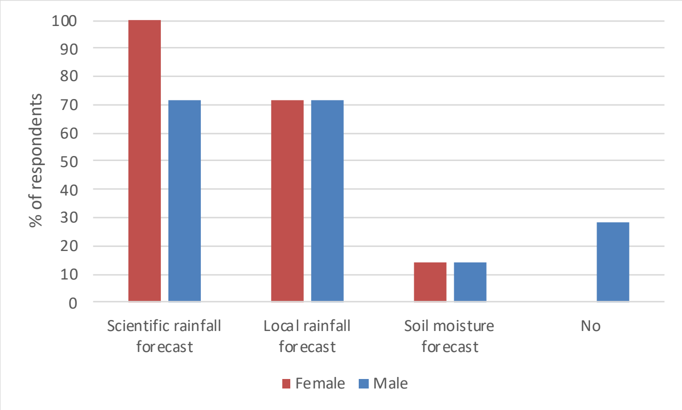

Figure 14 Use of the forecasts provided by the DROP app for agricultural decision-making by endline respondents.

Perception

During the baseline and endline study, farmers were asked whether they perceive the indigenous and scientific rainfall forecast to be aligned. Initially, the opinions were divided, and two women answered that they did not know. The majority of farmers answered sometimes. After training, all farmers answer *sometimes* (Figure A.VI - 5). The change in perception might be attributed to the influence of training, as farmers were able to view the local and scientific forecast in one app.

Both the accuracies of the scientific and the local forecast are perceived to be lower, after the DROP app training, with fewer farmers scoring it as (very) accurate (Figure 15a and b). This is likely attributed to a higher level of awareness and understanding after training, which is also shown in fewer females choosing *don't know*. Nevertheless, the farmers still score the forecasts as acceptable and higher, with the scientific forecast performing better than the local forecast.

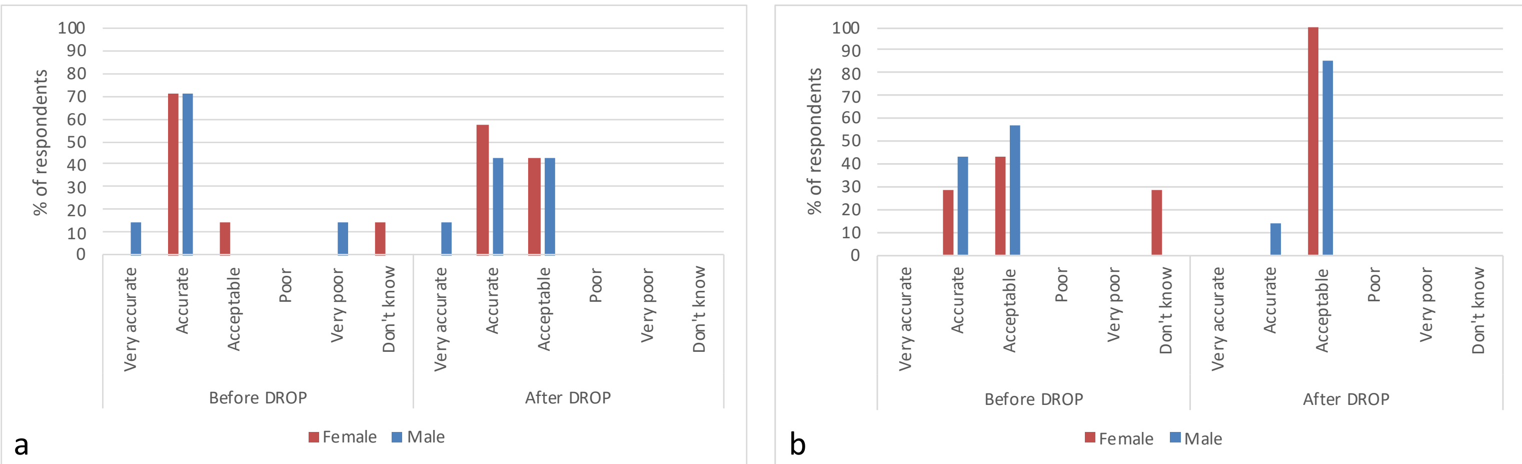

Figure 15 Scientific (a) and local (b) forecast accuracy, as perceived by the endline respondents.

The reported preference for indigenous forecasts has changed slightly, with one male farmer having a stronger preference for the local forecast and one female farmer becoming neutral instead of preferring the scientific forecast, after training (Figure 16). The majority of farmers (57.1% of women, 71.4% of men) still (strongly) prefer the scientific forecast. Furthermore, most endline respondents still prefer to receive an integrated forecast. Initially, only two respondents (men) preferred to receive separate forecasts. After training, there are respondents (2 men, 1 woman) who prefer to receive the forecasts separately.

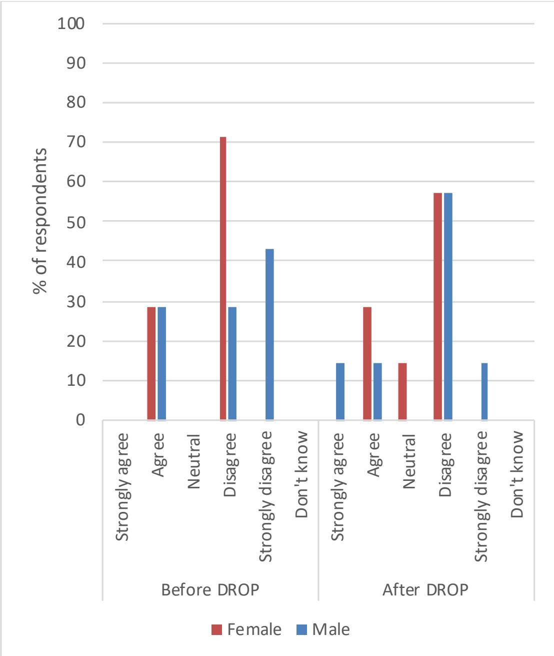

Figure 16 Statement: I prefer to use the indigenous forecast over the scientific forecast when possible.

Farmers were asked whether their trust in the forecasts has changed. All farmers, both male and female, report that they trust the scientific forecast more after training (Figure A.VI - 6a). Similarly, the majority of farmers (57.1% of women, 85.7% of men) have more trust in the local forecast after training (Figure A.VI - 6b). However, 42.9% of women and 14.3% of men remain neutral, indicating that their trust in the local forecast has not changed during the training.

In an open question, we asked farmers directly whether using the DROP app has changed their perception of local and scientific forecasts. Five farmers (42.8% of women, 28.6% of men) indicate that their perception of the local forecast has not changed. Women that indicate that their perception has changed mention that they now trust the local forecast a bit more, they understand it better, and they are more aware of the reliability. The men also mention that they are more aware of the reliability, and they trust it more because they can now see what other farmers think and because they see that it is sometimes aligned with the scientific forecast. Regarding the scientific forecast, seven farmers (42.9% of women, 57.1% of men) indicate that their perception has changed. Similar to the local forecast, farmers mention they trust the scientific forecast more (e.g., due to better access), that it helps distinguish rainfall intensity and that it enables them to blend forecasts to make decisions.

The majority of endline respondents mentioned no disadvantages of either the local or scientific forecasts provided by the DROP app. The advantages that are mentioned largely overlap with the advantages mentioned in the baseline study. An additional advantage of the local forecast in the DROP app is that it allows one to see whether an individual's predictions were right, as it shows the predictions by others, as shown in Table 10. Farmers appreciate that the forecasts show rainfall intensity. New disadvantages mentioned for the local forecast are that people could forget to submit their predictions and that farmers might not always agree with the local forecast. The challenges of the scientific forecast are that it is difficult to use for illiterate farmers and that it cannot be accessed on all phones.

Table 10 The (dis)advantages of the local and scientific forecast provided by the DROP app.

	Local forecast	Scientific forecast
Advantages	Rainfall intensity	Rainfall intensity
	Affordable	Accessible
	Allows to see whether their prediction was right	Decision-making
		Accurate
Disadvantages	People might forget to submit their forecast	Difficult to use for illiterate farmers
	Farmers might disagree with the local forecast	App does not work on all phones/not enough phones
	Short lead time	Accuracy
	Accuracy	

5 Discussion

This chapter first reflects on the results of this thesis and tries to put the results in perspective by comparing them to existing literature. Secondly, it discusses the limitations of the data and methods used in this research.

5.1 Reflection on Information Needs, Indigenous Knowledge, Local Forecast Skill, and Forecast Perception

This research aims to facilitate the development of gender-responsive WCIS by evaluating local and scientific forecasts used in Northern Ghana. To meet this objective, the differences between male and female farmers in information needs, indigenous knowledge, local forecast skill and forecast perception were analysed. By doing so, this research makes an important contribution to the provision of gender-disaggregated data, which is currently lacking (UN, 2019).

Weather and Climate Information Needs

The baseline study shows that both male and female farmers mostly need rainfall and soil moisture information for agricultural decision-making, which is in accordance with the findings of Sutanto et al. (2022) in the Northern Region of Ghana. Another important type of (agricultural) information for the farmers is information on crop/variety selection, which the farmers perceive to be even more important than soil moisture information. The majority of both men and women already receive rainfall and soil moisture information, and most of them rate the quality of this information as *good* to *very good*. Again, this corresponds to the results of Sutanto et al. (2022). However, it differs from a similar study in Khulna, Bangladesh, by Kumar et al. (2020), in which the majority of farmers perceived the quality of existing climate information much less positively (*poor* to *very poor*). This divergence might be partly caused by a difference in needs due to a difference in climate and climate-related hazards between the two countries.

Both male and female farmers mostly prefer receiving weather and climate forecasts with a 1-week lead time. This is in line with the findings of Kumar et al. (2021) in Bangladesh. On the other hand, it differs from the study of Sutanto et al. (2022), in which farmers in Northern Ghana mainly preferred to receive forecasts with a 2-3 day lead time. Furthermore, the result is opposed to the findings of Nyadzi et al. (2019), which showed that farmers in the Northern Region of Ghana prefer to receive forecasts with a 1-month lead time. Generally, the results show that men are more interested in forecasts with longer lead times (one month or longer), whereas more women prefer forecasts with shorter lead times (3 days or less). This might be because female farmers are responsible for daily household activities like cooking and drying farm produce, which require daily planning (Fieldwork note, 2022). The study of Henriksson et al. (2021) showed that more than twice as many female farmers as male farmers in Malawi do not use seasonal forecasts. However, they did not research whether this pattern was caused by different needs, preferences or a female lack of access to seasonal forecasts. Research in Mali indicates that gender inequality in decision-making power might play a role in the difference in forecast needs between male and female farmers (Carr & Onzere, 2018; Gumucio et al., 2020). Even though female farmers might farm their own piece of land, male family members might decide on e.g., the crop type, which could reduce the female farmers' need to receive seasonal forecasts.

The participating farmers mainly receive information via peer farmers, followed by radio and television. An equal number of male and female farmers receive information through peer farmers and radio, but more men receive information via television broadcasts. These results partly correspond to the study of Kumar et al. (2020), in which peer farmers were also the main source of information. However, in their research, radio was not found to be an important source of information. In Malawi, farmers do report frequently using the radio as a source of information (Henriksson et al., 2021). A minority of farmers also obtain information via SMS, NGOs, agricultural extension officers, the internet and newspapers. Multiple farmers indicate that they cannot read the SMS they receive, which is in accordance with the high level of illiteracy among respondents. Only a few men receive information via the internet, suggesting that farmers, especially females, have very limited access to smartphones. This is attested by Gumucio et al. (2020), Kumar et al. (2021) and Partey et al. (2020), who provide multiple reasons for the female lack of access to smartphones. Furthermore, women often cannot read the information provided via smartphones, due to gender inequalities in education.

Moreover, the results suggest that male farmers receive agricultural information more frequently than women. The majority of men receive information (*very) often*, while most women receive it only *sometimes*. This gender pattern is not in line with the findings of Diouf et al. (2019) in Senegal, where no significant difference in access was found between men and women. However, a gender difference in information access was found in other countries across Sub-Saharan Africa (Henriksson et al., 2021; Partey et al., 2020; Phiri et al., 2022). Furthermore, the results are in line with the findings from Gumucio et al. (2020) and Ngigi & Muange (2022), which show that in multiple African (and Asian) countries, women do not have the time to listen to radio broadcasts because they are responsible for household work and childcare. Thus, the division of tasks between men and women influences the capacity of the respective genders to access and thus also act on available agricultural information (Phiri et al., 2022). Regarding the best way of information dissemination, it can be disputed whether the internet (via smartphones) or radio and TV are better channels. While information dissemination via smartphones, as the DROP app does, allows for accessing information at any point in time, the lack of smartphones is an issue and so is the comprehensibility due to the high rate of illiteracy, especially for women. On the other hand, radio and TV allow for shared listening (Gumucio et al., 2020), thereby giving more people access to information. However, as previously mentioned, especially women might be unable to access the information at the right time, due to preoccupation with other tasks. This shows that the channels have both advantages and disadvantages, and that women are more likely to experience the latter. In the choice of dissemination channels, these advantages and disadvantages should be considered. Offering WCIS through a range of channels might be the best solution, as was also stated by Henriksson et al. (2021) and Warner et al. (2022).

Indigenous Knowledge, Local Indicators and Local Forecast Skill

On average, male farmers seem to have more indigenous knowledge than female farmers. Male farmers know and/or use more local indicators than female farmers; 3.6 versus 2.5 rainfall indicators and 2.4 versus 1.9 soil moisture indicators, for men and women respectively. As far as we are aware, no other studies have quantified differences in indigenous knowledge between male and female farmers.

In the baseline study, 34 distinct rainfall indicators were identified and documented in the three communities, Nabogu, Gushie and Diare. Most rainfall indicators fit into the categories *animals* (12 indicators) and *meteorology* (10 indicators). Based on the literature review and previous documentation of Snoeren (2020), the rainfall indicators are categorised into spatial scales. The majority of indicators are applied locally (21), followed by indicators applied globally (7) and regionally (6). This shows that WCIS that are, in part, based on indigenous knowledge cannot simply be copied from one region to another, as indicators are not present and/or do not have the same meaning everywhere. However, the global documentation of rainfall indicators does provide a basis for the expansion of WCIS incorporating indigenous knowledge to other regions.

Regarding soil moisture, 29 distinct indicators were documented. The soil moisture indicators are mainly used for monitoring (21 indicators), and not for prediction. The literature review on soil moisture indicators showed that there are very few studies that have researched the use of local indicators for soil moisture monitoring and prediction, despite the importance of soil moisture in agriculture (Asbjornsen et al., 2011; Sutanto et al., 2022.

The local rainfall forecasts made by male farmers (accuracy = 0.58, HK = 0.08) perform better than the forecast made by female farmers (accuracy = 0.44, HK = -0.11). This might be explained by men having more knowledge of local rainfall indicators than women. The male farmers' forecast accuracy is just merely below a score of 0.6, the level at which local forecasts are considered as highly skilled in the research of Bosdijk (2023). In the research of Fraas (2021), all HK values below 0.15 were considered as unable to discriminate between rain/no rain events, which suggests that both male and female farmers in Northern Ghana are unable to distinguish between rain and no rain events either. This is confirmed by the FAR score of both men and women, which shows that both groups over-forecast rainfall, with women doing so even more than men. Therefore, even though men perform slightly better than women, both genders are not able to properly forecast rainfall.

To put the local forecast skill in perspective, it is interesting to consider the skill of the scientific forecast. In the research of Bosdijk (2023), the skill of the scientific forecast from meteoblue that is provided by the DROP app was calculated. The scientific forecast has an accuracy that is higher than 0.7 an HK score of 0.44. Thus, it has a substantially higher accuracy and HK score than the local forecast of both male and female farmers. This shows that farmers of both genders could really benefit from using a scientific or hybrid forecast, as it would improve the reliability of the forecasts they use for agricultural decision-making.

Perception

Both male and female farmers use local forecasts more frequently than scientific forecasts, which corresponds to the findings of Nyadzi et al. (2019) in Northern Ghana. Female farmers seem to be more uncertain about the accuracy of forecasts, as a few women answered they don't know the accuracy, which might be due to a lack of knowledge of local weather forecasts and lack of access to scientific forecasts. Almost all male and female farmers already integrate local and scientific forecasts, and the majority of farmers prefer receiving forecasts that are already integrated, which is in line with the research of Nyadzi et al. (2022) in the Northern Region.

During the endline study, farmers' perceptions of local and scientific forecasts were researched again, to give insight into whether the introduction of the DROP app led to a change in perception. Male farmers checked the rainfall forecasts in the DROP app more frequently than female farmers. While all farmers claim to understand the rainfall forecasts, men were more positive about the comprehensibility than women. This might be linked to the lower education and literacy levels of women reported in the section on socio-demographic characteristics, as educated people have better language skills and higher technical proficiency (Henriksson et al., 2021). However, this seems to be contradicted by the fact that women reportedly understand the soil moisture forecast better than men.

All male farmers and two-thirds of female farmers claim that they started to use the scientific forecast more often, which corresponds to the findings of Kumar et al. (2021) from Bangladesh. However, when asked to indicate the frequency, the results for the female farmers suggest a slight decrease in the use of scientific forecasts. This discrepancy might be caused by the use of vague quantifiers (*rarely*, *often*, etc.). The meaning of vague quantifiers might vary per farmer, and it is possible that farmers (or translators) were inconsistent in their interpretation of the vague quantifiers in the baseline and endline study (Rocconi et al., 2020). For the local forecasts, the majority of farmers indicate that they use it *very often*, which means an increase in use for some farmers, and a decrease for others. Perhaps this can be explained by the fact that on the one hand, women were less dependent on the local forecast because of the higher accessibility of the scientific forecast (Kumar et al., 2021), but on the other hand, the local forecast was also more available perhaps leading to an increase of use by women with little indigenous knowledge. The same can be seen for men, but to a lesser extent.

The majority of farmers used the rainfall forecasts for agricultural decision-making. Farmers in Gbulung, who were introduced to the DROP app earlier in the rainy season, have used the weather information for sowing, weeding, fertilizer application and spraying herbicides, as described in Appendix VIII – Notes Field Visit Gbulung. The findings of Kumar et al. (2021) showed that farmers in Bangladesh use the provided weather information for similar activities. Moreover, it corresponds to the results of Gbangou et al. (2020), who showed that their coproduction experiment in Southern Ghana improved farm decisions. Besides using the rainfall information for agriculture, the farmers in the Northern Region of Ghana use the forecasts for daily activities like going to the market and cooking.

After training, farmers perceive the accuracies of the local and scientific forecasts to be lower. This could be due to a higher level of awareness, as attention was paid to the accuracy of forecasts during the training sessions. However, during the fieldwork, and FGDs particularly, we noticed that farmers struggle to give a score to the accuracy. Another cause for the change in perception could therefore be that farmers answer this question inconsistently because they are unsure. All farmers indicate that their trust in the scientific forecast has increased, while about two-thirds of farmers indicate to trust the local forecast more after training than before. This is likely linked to the fact that farmers now understand the reliability of the local forecast better, and because there is improved access to the scientific forecast, as mentioned by farmers. Furthermore, the result corresponds to the findings of Kumar et al. (2021): co-production of information services improves farmers' trust in forecasts. The majority of men and women still prefer to receive the scientific forecast over the local forecast and prefer to receive an integrated forecast.

5.2 Limitations

Fieldwork

This study was constrained by the time and resources (translators, transport) available. We left for the fieldwork in September, which was quite late, as the rainy season ends at the end of October/the beginning of November. Furthermore, multiple challenges regarding translation and transport, described in the fieldwork report (Appendix IX – Fieldwork Report) arose during the fieldwork that led to delays and reduced efficiency of data collection. Therefore, DROP app training in all three communities occurred late into the rainy season. Consequently, farmers could only enter forecasts and observations for a short period, resulting in a short rainfall prediction and observation dataset. To overcome this, the (longer) dataset from Lefèvre (2022) was used to calculate the skill of the local forecasts created by male and female farmers. Even though this is not based on the communities of the baseline and endline study, it still provides insight into differences in forecast skill from communities that are very close to the three communities that are the main focus of this research.

Moreover, because the study was conducted late into the rainy season, the influence of the provision of forecasts through the DROP app on agricultural decision-making was difficult to research, as many of the agricultural production stages had already passed. Since the endline study was done shortly after the baseline study, we cannot determine the long-term impacts of the information provided.

Furthermore, due to the limited time available, the sample size was set to 60 farmers. These farmers were selected by farmer leaders, which we asked to choose a variety of farmers and select an equal number of men and women. To find statistically robust differences between men and women, this sample size might be too small, but it is enough to illuminate important differences and similarities. Due to the delays, we were unable to conduct the endline study in Gushie and Diare. Therefore, the sample size of the endline study is even smaller. Consequently, the results of the endline should be interpreted with caution.

As many farmers did not speak English (fluently), translation was necessary for all fieldwork activities. The baseline and endline study questionnaires were held as interviews, in which a translator provided simultaneous interpretation between English and Dagbani. However, this creates the risk of translation bias. In this research, translation was done by three people. Translators might have different interpretations of the questions than we and the other translators and might interpret the answers in a different way as well, resulting in translation bias. To limit this, we discussed all questions in depth with the translators beforehand, to make sure that each of the translators understood our meaning. However, translation bias is still possible.

Literature review

In the literature review, two academic research databases were used: Scopus and Web of Science. The databases together cover a large part of peer-reviewed articles, which were of interest to this research. Perhaps more relevant articles could have been found if other databases had been used as well. However, it was decided to not include more databases as the documentation of indicators was not the main aim of this research. Furthermore, screening articles is time-consuming, and time was limited.

Moreover, the choice of search queries influences the articles found in the literature search. For rainfall, it was decided to use the same search queries as Snoeren (2020), as the literature search aimed to complement her documentation. For soil moisture, the search query was chosen after careful consideration and trying out other search strings. More general search strings resulted in many irrelevant articles. Therefore, the search string was kept as specific as possible. Limiting the search to English articles might have reduced the number of relevant articles. Especially in South America, Spanish is the common language of communication. Therefore, by excluding Spanish articles, indicators in South America might be missed, resulting in indicators classified as local or regional, that are in fact global.

In addition, the classification method can be disputed. In this research, indicators were classified as either regional or global, if the signal and outcome prediction of indicators reported in two different areas are similar. However, in some cases, the similarity was a so-called ‘grey area’. For example, in one article covering a certain region, a specific bird species could be a signal for rainfall. If in another article, the bird species is not specified but does have the same outcome prediction, the indicator was not seen as similar. However, it could be that the person referring to ‘birds’ in general, is actually referring to one or a few specific species, which might be the same as in the article. Furthermore, sometimes there were very slight differences in outcome prediction. In these cases, the indicators were still seen as similar.

Skill assessment

It is important to note that we are not fully certain about the identity of the farmers who submitted forecasts on each account. We removed double forecasts by one user for the same day. However, it is possible that these submissions were done by multiple farmers. As farmers are sharing phones, they might forget to log out and use each other’s accounts to submit forecasts. Therefore, it is possible that some forecasts submitted by a male user are actually submitted by a female farmer, and vice versa. This reduces the reliability of the outcome of our gender-disaggregated skill assessment.

Secondly, the skill assessment for male farmers is based on a larger number of submissions and a larger number of persons than the skill assessment for female farmers. Therefore, while it provides some preliminary insight, it is not a fair comparison of both genders.

Thirdly, multiple integration methods, like the statistical integration method suggested by Gbangou et al. (2021), use local indicators to create a hybrid forecast. Therefore, the skill of the indicators used for the local forecast should be assessed. However, as the DROP app did not yet contain a section where farmers could indicate which indicators they observed, we used a questionnaire to retrieve data on the observation of indicators. Though, due to the delay in training and the language barrier, only very little data on the observation of indicators was retrieved. Therefore, in this research, we compare the skill of men and women based on just the local forecast skill, not the indicators that the forecast is based on.

Overall, due to the short dataset and its uncertainties, the results must be treated cautiously. More fieldwork is needed to collect more data to draw valid conclusions.

6 Conclusion

Farmers engaged in rainfed farming are vulnerable to climate change. They require reliable weather information to effectively adapt to the impacts of climate change. WCIS with hybrid forecasts based on scientific and indigenous knowledge have the potential to provide this. However, the provision of information is only effective when it is tailored to the needs of its users. Despite women being important stakeholders in agriculture, their needs and preferences are rarely considered in the development of WCIS. This study tries to bridge this gap by collecting gender-disaggregated data on information needs and access, indigenous knowledge and local forecast skill, and perception of forecasts. The findings of this study indicate that in Northern Ghana, the information needs of men and women largely overlap. Both male and female farmers prefer to receive information on rainfall, crop (variety) selection and soil moisture. However, female farmers have less access to this information. To reduce gender inequality in information access, a (selection of) dissemination method(s) needs to be chosen carefully. Men and women use local forecasts more often than scientific forecasts, but men generally have more indigenous knowledge of indicators for local forecasting than women. The majority of rainfall indicators are applied locally, but some are used across Sub-Saharan Africa or globally. Although the results have to be treated with caution due to the limitations of the dataset, the skill assessment shows that men are better at forecasting rainfall than women. However, both local forecast performances are low and thus both genders would greatly benefit from scientific or hybrid rainfall forecasts that have higher accuracy. Initially, male and female farmers perceived both scientific and local forecasts to have at least an acceptable accuracy and were aware of the advantages and disadvantages of both forecasts. After the introduction of the DROP app, farmers used scientific forecasts more frequently, and farmers trust both forecast types more. However, the perceived accuracies of both forecasts are lower, likely due to an increase in awareness. Farmers indicate that the forecasts provided by the DROP app assisted in their decision-making, and that they would like to receive integrated forecasts. While this thesis provides useful insights for the development of a gender-responsive WCIS, future studies must collect more gender-disaggregated data to ensure that male and female farmers in the Global South benefit from the WCIS equally.

7 Recommendations

Avenues for future research include collecting more (gender-disaggregated) indicator observations and local forecast data, to draw more robust conclusions on the forecast skill of male and female farmers and to enable the integration of local and scientific forecasts.

Secondly, further analysis using t-tests is needed to assess whether differences between men and women in Northern Ghana are statistically significant. Besides gender, other variables, like age, ethnicity, education, and income can determine the need for and access to information as well (Diouf et al., 2019; Gumucio et al., 2020; Henriksson et al, 2021). Statistical analysis should be performed to identify the most important factors (Diouf et al., 2019).

Thirdly, future studies should focus on information dissemination channels. In this research, farmers were asked through which channels they receive information, but not what their preferred channel is. The results indicate that there are gender differences in access to information and showed that information channels have both advantages and disadvantages. Accordingly, more research is needed to find ways to increase women's access to information. Moreover, combining channels for information dissemination should be investigated.

Fourthly, the long-term impacts of the implementation of WCIS should be assessed, as there is limited literature on this topic (Gumucio et al., 2022; Kumar et al., 2021). The endline study provides insight into how the DROP app affects farmers' decision-making and the benefits they experience. However, the training sessions occurred late into the rainy season and the endline study was carried out shortly after the training. Therefore, the influence on decision-making was minimal and only short-term impacts are found.

Lastly, the current literature on the weather and climate information needs of farmers is mainly focused on Sub-Saharan Africa (Gumucio et al. 2020; Warner et al., 2022). However, information needs differ per location. Furthermore, social norms and gender dynamics that lead to differences between men and women in needs are also location-specific. As gender inequality is a global problem, it is imperative that similar research is conducted in other regions, especially in the Global South.

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Appendix I – Baseline Study Questionnaire

This Appendix contains the questionnaire that was used in the baseline study.

Baseline study questionnaire

The objective of this interview is to document the local forecast indicators used in rural communities in Northern Ghana and to get an understanding of the perception of farmers on indigenous and scientific forecasting. This study is designed for academic research and therefore your opinion is very important. I assure you that your answers are solely used for research purposes, and not for any financial or business purpose. I assure you that there is no risk involved with participating in this interview and there is no direct benefit to your participation. If you do not want to answer a question, you are free to decline. You are also free to stop participating in the interview when the questions make you feel uncomfortable. Your answers will be included in the results, but it will not be possible to identify you or your answers in the report.

Enter a date *

yyyy-mm-dd

What is the name of your community? *

- ○ Nabogu
- ○ Gushie
- ○ Diari

What is your name? *

What is your phone number?

Section 1 (S1): Demographic information of farmer

S1Q1. What is your gender? *

- ○ Male
- ○ Female

S1Q2. What is your age? *

- < 30 years
- 30 - 40 years
- 40 - 50 years
- 50 - 60 years
- > 60 years

S1Q3. What is your household size? *

Household = the number of people under your care

- 1 - 5 persons
- 6 - 10 persons
- 11 - 15 persons
- 16 - 20 persons
- 21 - 25 persons
- > 25 persons

S1Q4. What is your educational level? *

- No education
- Primary education (elementary/primary school)
- Middle School/Junior High level
- Senior High School
- Tertiary education
- Non-formal education

S1Q5. Are you literate? *

- Yes (literate)
- No (illiterate)
- Somehow (partially literate)
- Don't know

S1Q6. Are you the land-owner of your farm? *

- Yes
- No

S1Q7. What is the size of your farm (in acres)? *

- < 1 acre
- 1 - 1.9 acres
- 2 - 2.9 acres
- 3 - 3.9 acres
- 4 - 4.9 acres
- 5 - 6 acres
- > 6 acres

If more than 6 acres, how many acres do you farm?

S1Q8. Do you have off-farm income? *

- Yes
- No

S1Q8. If yes, how much is your off-farm income?

- Much less than my income from farming
- Less than my income from farming
- Equal to my income from farming
- More than my income from farming
- Much more than my income from farming

S1Q9. Do you also have animals for farming? *

- Yes
- No

S1Q10. How many years of farming experience do you have? *

- 1 - 5 years
- 6 - 10 years
- 11 - 15 years
- 15 - 20 years
- > 20 years

S1Q11. What/which crops do you grow?

- [ ] Maize
- [ ] Rice
- [ ] Pepper
- [ ] Yam
- [ ] Beans
- [ ] Other

S1Q12. If other, what other crops do you grow?

Section 2 (S2): Agricultural information

S2Q1. Do you have access to any agricultural information that plays a role in your farming decision-making? *

- ◯ Yes
- ◯ No
- ◯ Don't know

S2Q2. If yes, how do you receive the agricultural information? *

- [ ] Television
- [ ] Radio
- [ ] Internet
- [ ] SMS
- [ ] Peer farmers
- [ ] NGOs or other formal contacts
- [ ] Newspapers
- [ ] Other

S2Q2. If other, please specify from which source you receive agricultural information.

S2Q3. If you receive agricultural information via SMS, what is the source?

- [ ] MTN
- [ ] Vodafone
- [ ] Gasip
- [ ] Don't know
- [ ] Other

If other, please specify.

S2Q3. If no, why don't you receive agricultural information?

S2Q4. How often do you receive agricultural information?

- ○ Very often
- ○ Often
- ○ Sometimes
- ○ Rarely
- ○ Never

S2Q5. What kind of agricultural information do you receive?

- [ ] Weather (rainfall) forecasts
- [ ] Soil moisture
- [ ] Input prices and availability (fertilizer, pesticides, seeds)
- [ ] Crop/variety selection
- [ ] Disease control
- [ ] Market prices
- [ ] Water availability
- [ ] Others
- [ ] No

If 'others', what kind of weather information do you receive? *

S2Q6. How would you rate the quality of information you receive in each case?	Very good	Good	Acceptable	Poor	Very poor	No opinion
Water availability	○	○	○	○	○	○

Weather (rainfall) forecasts	○	○	○	○	○	○
Input prices and availability	○	○	○	○	○	○
Crop/variety selection	○	○	○	○	○	○
Disease control	○	○	○	○	○	○
Market price	○	○	○	○	○	○
Soil moisture	○	○	○	○	○	○
Specified information	○	○	○	○	○	○

S2Q7. How would you rate the significance of weather information you receive in each case?	Most important	Very important	Important	Slightly important	Not important	No opinion
Water availability	○	○	○	○	○	○
Weather (rainfall) forecasts	○	○	○	○	○	○
Input prices and availability	○	○	○	○	○	○
Crop/variety selection	○	○	○	○	○	○
Disease control	○	○	○	○	○	○
Market price	○	○	○	○	○	○
Soil moisture	○	○	○	○	○	○
Specified information	○	○	○	○	○	○

S2Q8. Do you need more (agricultural) information? If yes, please specify.

S2Q9. How often do you depend on weather (rainfall) information for agricultural decision-making? *

- Always
- Often
- Sometimes
- Rarely
- Never

S2Q10. How often do you depend on soil moisture information for agricultural decision-mkaing? *

- Always
- Often
- Sometimes
- Rarely
- Never

S2Q11. How would you rate the quality/reliability of the information sources?	Very good	Good	Acceptable	Poor	Very poor	No opinion
Television	○	○	○	○	○	○
Radio	○	○	○	○	○	○
Internet (smartphone/tablet)	○	○	○	○	○	○
Peer farmers	○	○	○	○	○	○
NGOs or other formal contacts	○	○	○	○	○	○
Newspaper(s)	○	○	○	○	○	○
SMS	○	○	○	○	○	○
Specified source(s)	○	○	○	○	○	○

Section 3 (S3): Soil moisture/rainfall data

S3Q1. Are you aware of the concept of soil moisture? *

- Yes
- No

S3Q2. Do you take soil moisture information into account for agricultural decision-making? *

- Yes
- No
- Don't know

S3Q3. How important is soil moisture information for the decision-making on the following farming practices?	Extremely significant	Very significant	Significant	Not significant	No opinion
Land preparation					
Sowing					
Fertilizer application					
Weed control					
Pest control					
Harvesting					
Crop varieties					
Other					

S3Q4. If you use soil moisture information for the decision-making on other farming practices, please specify which.

S3Q5. Do you take rainfall (precipitation) information into account for agricultural decision-making? *

- ◯ Yes
- ◯ No
- ◯ Don't know

S3Q6. How important is rainfall information for the decision-making on the following farming practices?	Extremely significant	Very significant	Significant	Not significant	No opinion
Land preparation	◯	◯	◯	◯	◯
Sowing	◯	◯	◯	◯	◯
Fertilizer application	◯	◯	◯	◯	◯
Weed control	◯	◯	◯	◯	◯
Pest control	◯	◯	◯	◯	◯
Harvesting	◯	◯	◯	◯	◯
Crop varieties	◯	◯	◯	◯	◯
Others	◯	◯	◯	◯	◯

S3Q7. If you use rainfall information for the decision-making on other farming practices, please specify which.

S3Q8. Do you have any additional comments?

Section 4 (S4): Information needs

S4Q1. Do you think that weather information is important to make agricultural decisions? *

- ◯ Strongly agree
- ◯ Agree
- ◯ Neutral
- ◯ Disagree
- ◯ Strongly disagree

S4Q2. What kind of information do you need to make agricultural decisions? *

- ☐ Rainfall
- ☐ Temperature
- ☐ Humidity
- ☐ Storm
- ☐ Soil moisture
- ☐ Other

S4Q2. If other, please specify.

S4Q3. How advanced information do you need for farming-related decision-making? *

Lead time is the time between when the forecast is given and the occurrence of the phenomena that were predicted

- ☐ Today (Real time)
- ☐ Tomorrow (1 day lead time)
- ☐ Day after tomorrow (2 day lead time)
- ☐ 3 day lead time
- ☐ Next week (1-week lead time)
- ☐ Two weeks (2-week lead time)
- ☐ Next month (1 month lead time)
- ☐ Seasonal forecast (3-month lead time)

S4Q4. Do you have any additional comments?

Section 5 (S5): Weather forecasts and reliability

S5Q1. Do you use indigenous forecasting? *

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

S5Q2. If you use indigenous forecasting, who makes the indigenous forecast?

- ☐ I make it myself
- ☐ Rainmaker in my community
- ☐ Other

S5Q2. If other, who creates the indigenous forecast?

S5Q3. Who taught you how to use indicators for indigenous forecasts? *

- ☐ Father
- ☐ Mother
- ☐ Grandfather
- ☐ Grandmother
- ☐ Other relative
- ☐ Agricultural officer
- ☐ Other farmers
- ☐ Other

If other, how did you learn to use indicators for indigenous forecasting?

S5Q4. Which indicators do you use to predict rainfall and how?

In the table (S5Q4) provided on paper, please indicate the name of the indicators, their signals, the month/period in which the indicator is observed, and what the meaning of the indicator is. Please fill in only indicators that you use. If you use less than 8 indicators, please leave the other fields blank.

S5Q5. Which indicators do you use to predict soil moisture and how?

In the table (S5Q5) provided on paper, please indicate the name of the indicators, their signals, the month/period in which the indicator is observed, and what the meaning of the indicator is. Please fill in only indicators that you use. If you use less than 8 indicators, please leave the other fields blank.

Which indicators do you use to predict rainfall and how?	Indicator’s name	Indicator’s signal	Month/period in which you observe the indicator	Meaning of the indicator/outcome
Indicator 1				
Indicator 2				
Indicator 3				
Indicator 4				
Indicator 5				
Indicator 6				
Indicator 7				
Indicator 8				

Which indicators do you use to predict soil moisture and how?	Indicator’s name	Indicator’s signal	Month/period in which you observe the indicator	Meaning of the indicator/outcome
Indicator 1				
Indicator 2				
Indicator 3				
Indicator 4				
Indicator 5				
Indicator 6				
Indicator 7				
Indicator 8				

S5Q6. Do you use scientific forecasts? *

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

S5Q7. I prefer to use the indigenous forecast over the scientific forecast when possible. *

- ◯ Strongly agree
- ◯ Agree
- ◯ Neutral
- ◯ Disagree
- ◯ Strongly disagree
- ◯ I don't know

S5Q8. Do you use integrated forecasts? (By integrating indigenous and scientific forecasts yourself) *

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

S5Q9. If you use both indigenous and scientific forecasts, how do you combine the forecasts? *

- ☐ Put them together as one forecast
- ☐ Compare both and choose one based on my experience (complementarily)
- ☐ I don't know
- ☐ Other

S5Q9. If other, please specify.

S5Q10. Are the indigenous and scientific forecasts aligned?

- Always
- Very often
- Sometimes
- Rarely
- Never
- Don't know

S5Q11. How accurate do you think the indigenous forecast is? *

- Very accurate
- Accurate
- Acceptable
- Poor
- Very poor
- Don't know

S5Q12. How accurate do you think the scientific forecast is? *

- Very accurate
- Accurate
- Acceptable
- Poor
- Very poor
- Don't know

S5Q13. For decision-making, would you prefer to receive an integrated scientific and indigenous forecast rather than separate? *

- Yes
- No
- Maybe
- Don't know

S5Q14. I will accept the information from an integrated forecast more because it combines the best of scientific and indigenous forecasts. *

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree
- I don't know

S5Q15. I prefer to have an integrated forecast that is already combined than using IF and SF complementarily. *

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree
- I don't know

S5Q16. What are the benefits of indigenous forecasts?

S5Q17. What do you think are disadvantages of indigenous forecasts (if any)?

S5Q18. What are the benefits of scientific forecasts?

S5Q19. Do you think there are disadvantages of scientific forecasts? *

- Yes
- No
- Don't know/Can't tell

S5Q19. If yes, what do you think are the disadvantages of scientific forecasts? *

- [ ] Not reliable forecast
- [ ] Too difficult to understand the forecast
- [ ] I do not trust the forecast
- [ ] No access to scientific forecast
- [ ] Other

S5Q19. If other, please specify.

S5Q20. What is the quality of rainfall information?	Very good	Good	Acceptable	Poor	Very poor	No opinion
Indigenous forecast on rainfall *	○	○	○	○	○	○
Scientific forecast on rainfall *	○	○	○	○	○	○

S5Q21. What is the quality of soil moisture information?	Very good	Good	Acceptable	Poor	Very poor	No opinion
Indigenous forecast on soil moisture	○	○	○	○	○	○
Scientific forecast on soil moisture	○	○	○	○	○	○

S5Q22. Do you have any additional comments? Please write them here. . Do you have any additional comments?

Appendix II – Endline Study Questionnaire

This Appendix contains the questionnaire that was used in the endline study.

Endline study questionnaire

What is is your name?

Enter a date

yyyy-mm-dd

What is your phone number?

Community

- ◯ Nabogu
- ◯ Gushie
- ◯ Diari

Section 1: DROP App general

---

1. Did you have access to the DROP App information?

- ☐ Yes, via my own smartphone
- ☐ Yes, via a smartphone provided by the project
- ☐ Yes, someone who has the DROP App told me about the forecasts
- ☐ Yes, I used someone else's phone to look at the DROP App
- ☐ No, I did not have access to the DROP App

Who told you about the forecast from the DROP App?

Who's phone did you use to look at the DROP App?

---

2. Are you currently receiving forecasts from the DROP App?

- ◯ Yes
- ◯ No

If no, why do you not have access to the forecasts from the DROP App?

---

3. How often do you look at the DROP App scientific rainfall forecast?

- ◯ Every day
- ◯ Every other day
- ◯ Every 3/4 days
- ◯ Once a week
- ◯ Once every two weeks
- ◯ Less than every two weeks
- ◯ Never

4. How often do you input and look at the indigenous rainfall forecast in the DROP App?

- ◯ Every day
- ◯ Every other day
- ◯ Every 3/4 days
- ◯ Once a week
- ◯ Once every two weeks
- ◯ Less than every two weeks
- ◯ Never

5. How often do you input and look at the soil moisture forecast in the DROP app?

- ◯ Every day
- ◯ Every other day
- ◯ Every 3/4 days
- ◯ Once a week
- ◯ Once every two weeks
- ◯ Less than every two weeks
- ◯ Never

6. Did you share the forecast with other farmers?

Multiple options possible

- ☐ Yes, I shared the indigenous rainfall forecast
- ☐ Yes, I shared the scientific rainfall forecast
- ☐ Yes, I shared the soil moisture forecast
- ☐ No

7. With whom did you share the forecast?

- [ ] Husband/wife
- [ ] Children
- [ ] Other relatives
- [ ] Peer farmer
- [ ] Other

Section 2: DROP App quality and reliability

---

1. Was the scientific rainfall forecast easily understandable?

- ○ Very easy
- ○ Easy
- ○ Not easy
- ○ Very difficult
- ○ NA

2. Was the indigenous rainfall forecast easily understandable?

- ○ Very easy
- ○ Easy
- ○ Not easy
- ○ Very difficult
- ○ NA

3. Was the soil moisture forecast easily understandable?

- ○ Very easy
- ○ Easy
- ○ Not easy
- ○ Very difficult
- ○ NA

4. After training, do you feel like you understand the scientific forecast uncertainties (better)?

- ○ Strongly agree
- ○ Agree
- ○ Neutral
- ○ Disagree
- ○ Strongly disagree
- ○ Don't know

5. How accurate is the scientific rainfall forecast provided by the DROP App?

- ◯ Very accurate
- ◯ Accurate
- ◯ Acceptable
- ◯ Poor
- ◯ Very poor
- ◯ Don't know

6. How accurate is the indigenous rainfall forecast provided by the DROP App?

- ◯ Very accurate
- ◯ Accurate
- ◯ Acceptable
- ◯ Poor
- ◯ Very poor
- ◯ Don't know

7. How accurate is the soil moisture forecast provided by the DROP app?

- ◯ Very accurate
- ◯ Accurate
- ◯ Acceptable
- ◯ Poor
- ◯ Very poor
- ◯ Don't know

8. Did you use the forecasts for agricultural decision-making?

Multiple choice possible

- ☐ Yes, the scientific rainfall forecast
- ☐ Yes, the indigenous rainfall forecast
- ☐ Yes, the soil moisture forecast
- ☐ No

9. If yes, for what decisions did you use the app?

____

10. Are you satisfied with the performance of the DROP App?	Very satisfied	Satisfied	Neutral	Unsatisfied	Don't know
Overall satisfaction DROP App	◯	◯	◯	◯	◯
Availability/accessibility DROP App	◯	◯	◯	◯	◯
Timeliness of information	◯	◯	◯	◯	◯
Comprehensibility of information	◯	◯	◯	◯	◯

Specificity of information for decision-making	◯	◯	◯	◯	◯
Actionability of information	◯	◯	◯	◯	◯
Credibility of information	◯	◯	◯	◯	◯

11. I am better able to plan my farming activities after the DROP App training.

- ◯ Strongly agree
- ◯ Agree
- ◯ Neutral
- ◯ Disagree
- ◯ Strongly disagree
- ◯ Don't know

12. Do you think the DROP App is better than other sources providing similar information? Please explain.

____

13. Do you have any feedback on the DROP App?

____

14. Do you have any additional comments?

____

Section 3: Comparing the Indigenous and Scientific Forecast

____

1. Do you use indigenous forecasting (your own indigenous forecast/indigenous forecast from DROP app)?

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

2. Do you use a scientific forecast (DROP App or other)?

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

3. I prefer to use the indigenous forecast over the scientific forecast when possible.

- ◯ Strongly agree
- ◯ Agree
- ◯ Neutral
- ◯ Disagree
- ◯ Strongly disagree
- ◯ Don't know

4. Did you start using a scientific forecast more often because of the DROP App?

- ◯ Yes
- ◯ No
- ◯ Don't know

5. Do you use integrated forecasts (by integrating the indigenous and scientific forecast)?

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

6. If you use both, how do you combine the forecasts?

- ◯ Put them together as one forecast
- ◯ Compare both and choose one based on my experience (complementarily)
- ◯ I don't know
- ◯ Other

If other, please specify.

---

7. Are the indigenous and scientific forecasts often aligned?

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ Don't know

8. For decision-making, would you prefer to receive an integrated scientific and indigenous forecast rather than separate?

- ◯ Yes
- ◯ No
- ◯ Maybe
- ◯ Don't know

9. After using the DROP App, I trust the scientific forecast better.

- ◯ Strongly agree
- ◯ Agree
- ◯ Neutral
- ◯ Disagree
- ◯ Strongly disagree
- ◯ Don't know

10. After using the DROP App, I trust the indigenous forecast better.

- ◯ Strongly agree
- ◯ Agree
- ◯ Neutral
- ◯ Disagree
- ◯ Strongly disagree
- ◯ Don't know

11. Has using the app changed the way you think about indigenous forecasts? Please explain.

___

12. What are advantages of the indigenous forecast from DROP app?

___

13. What are disadvantages of the indigenous forecast from DROP app?

___

14. Has using the app changed the way you think about scientific forecasts? Please explain.

___

15. What are advantages of the scientific forecast from DROP app?

___

16. What are disadvantages of the scientific forecast from DROP app?

___

Appendix III – Overview of Fieldwork Activities

This Appendix gives an overview of the fieldwork activities.

SEP2022

SUN	MON	TUE	WED	THU	FRI	SAT
				01	02	03
04	05 Meeting Jamaldeen (UDS)	06 Meeting Dr. Bizoola + Richard (UDS)	07	08	09	10
11	12 Meeting chiefs of communities	13	14	15	16	17 First introduction Marin to Gbulung
18 Marin to Gbulung	19 Marin to Gbulung	20 Marin to Gbulung	21 All to Gbulung	22	23 Original planned departure date to communities	24
25 Meeting German scientists	26 1st meeting Prof. Gordona + workshop by the German scientists	27 Departure to Nabogu + first introduction to farmer leaders in Nabogu and Nakpanzoo	28 FGD in Nabogu	29 Questionnaires in Nabogu	30 Questionnaires in Nabogu	

Figure A.III - 1 Overview of fieldwork activities in September.

OCT2022

SUN	MON	TUE	WED	THU	FRI	SAT
						01 Questionnaires in Nabogu
02	**03** Training in Nabogu	**04** Training in Nabogu + FGD in Gushie	**05**	**06** Training in Nakpanzoo + training in Nabogu	**07** Training in Nabogu	**08** Questionnaires in Gushie
09 FGD in Diare + training in Nakpanzoo	**10** Training in Gushie + Training in Nabogu	**11** Training in Gushie + Questionnaires in Diare	**12** Training in Gushie	**13**	**14**	**15** Questionnaires in Diare
16	**17**	**18** Questionnaires Diare	**19** Training Diare	**20** Training Diare	**21**	**22**
23 Training Diare	**24** Training Diare + recap in Yapalsi	**25** Gushie recap + Yapalsi recap & motivation	**26** Final recap in Nakpanzoo & endline in Nabogu + Gushie motivation	**27** Endline in Nabogu	**28** Final recap in Gbulung	**29**
30	**31**					

Figure A.III - 2 Overview of fieldwork activities in October.

Appendix IV – Systematic Literature Review

This Appendix gives an overview of the steps taken during the literature review.

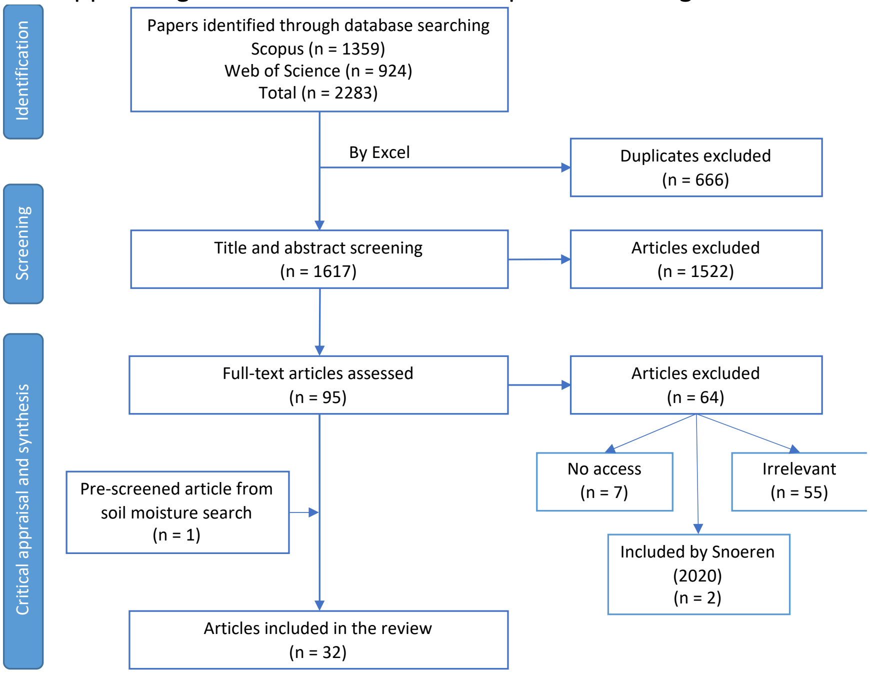

Figure A.IV - 1 Schematic overview of the systematic literature review on rainfall indicators.

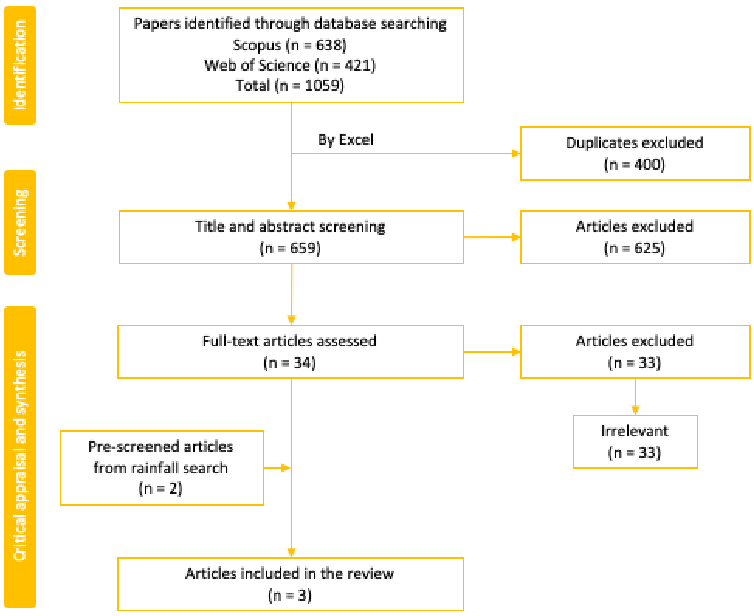

Figure A.IV - 2 Schematic overview of the systematic literature review on soil moisture indicators.

Appendix V – Baseline Study Results

This Appendix provides additional information on the results presented in Chapter 4.1 to Chapter 4.6.1.

V.A – Socio-Demographic Characteristics of Farmers

Table A.V - 1 Socio-demographic information of respondents, per community.

		Nabogu		Gushie		Diare		Total	
Variable	**Category**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Age (years)	< 30	2	10.00%	1	5.00%	2	10.00%	5	8.33%
	30 - 40	14	70.00%	4	20.00%	8	40.00%	26	43.33%
	40 - 50	3	15.00%	7	35.00%	7	35.00%	17	28.33%
	50 - 60	1	5.00%	4	20.00%	2	10.00%	7	11.67%
	> 60		0.00%	4	20.00%	1	5.00%	5	8.33%
Household size	1 - 5	10	50.00%		0.00%	2	10.00%	12	20.00%
	6 - 10	1	5.00%	9	45.00%	9	45.00%	19	31.67%
	11 - 15	5	25.00%	7	35.00%	3	15.00%	15	25.00%
	16 - 20	3	15.00%	3	15.00%	1	5.00%	7	11.67%
	21 - 25		0.00%	1	5.00%	3	15.00%	4	6.67%
	> 25	1	5.00%		0.00%	2	10.00%	3	5.00%
Educational level	None	8	40.00%	14	70.00%	12	60.00%	34	56.67%
	Non-formal		0.00%	2	10.00%		0.00%	2	3.33%
	Primary	4	20.00%	1	5.00%	3	15.00%	8	13.33%
	Middle/Junior	2	10.00%		0.00%	3	15.00%	5	8.33%
	Senior	4	20.00%	2	10.00%	2	10.00%	8	13.33%
	Tertiary	2	10.00%	1	5.00%		0.00%	3	5.00%
Literacy	No	12	60.00%	14	70.00%	13	65.00%	39	65.00%
	Partially	2	10.00%	3	15.00%	2	10.00%	7	11.67%
	Yes	6	30.00%	3	15.00%	5	25.00%	14	23.33%
Land ownership	Yes	11	55.00%	5	25.00%	15	75.00%	31	51.67%
	No	9	45.00%	15	75.00%	5	25.00%	29	48.33%
Farm size (acres)	1 - 1.9		0.00%		0.00%	1	5.00%	1	1.67%
	2 - 2.9	2	10.00%		0.00%		0.00%	2	3.33%
	3 - 3.9	1	5.00%	2	10.00%	2	10.00%	5	8.33%
	4 - 4.9	3	15.00%	3	15.00%	3	15.00%	9	15.00%
	5 - 6	5	25.00%	3	15.00%	2	10.00%	10	16.67%
	> 6	9	45.00%	12	60.00%	12	60.00%	33	55.00%
Off-farm income	Yes	15	75.00%	12	60.00%	14	70.00%	41	68.33%
	No	5	25.00%	8	40.00%	6	30.00%	19	31.67%
Farm animals	Yes	11	55.00%	8	40.00%	9	45.00%	28	46.67%
	No	9	45.00%	12	60.00%	11	55.00%	32	53.33%

Farm experience (years)	1 - 5	4	20.00%	1	5.00%	3	15.00%	8	13.33%
	6 - 10	4	20.00%	4	20.00%	4	20.00%	12	20.00%
	11 - 15	3	15.00%	2	10.00%	1	5.00%	6	10.00%
	16 - 20	2	10.00%		0.00%	3	15.00%	5	8.33%
	> 20	7	35.00%	13	65.00%	9	45.00%	29	48.33%

Table A.V - 2 Crops cultivated by respondents.

	Female		Male		Total	
Crop	**N**	**%**	**N**	**%**	**N**	**%**
Maize	24	80.00%	30	100.00%	54	90.00%
Rice	22	73.33%	27	90.00%	49	81.67%
Pepper	1	3.33%	1	3.33%	2	3.33%
Yam	0	0.00%	8	26.67%	8	13.33%
Beans	24	80.00%	29	96.67%	53	88.33%
Groundnut	24	80.00%	16	53.33%	40	66.66%
Okra	4	13.33%	1	3.33%	5	8.33%
Yellow milo	1	3.33%	3	10.00%	4	6.67%
Watermelon	2	6.67%	2	6.67%	4	6.67%
Cassava	0	0.00%	2	6.67%	2	3.33%
Cabbage	0	0.00%	1	3.33%	1	1.67%
Vegetables	1	3.33%	0	0.00%	1	1.67%
Average	**3.4**		**4**		**3.7**	

V.B – Information Needs

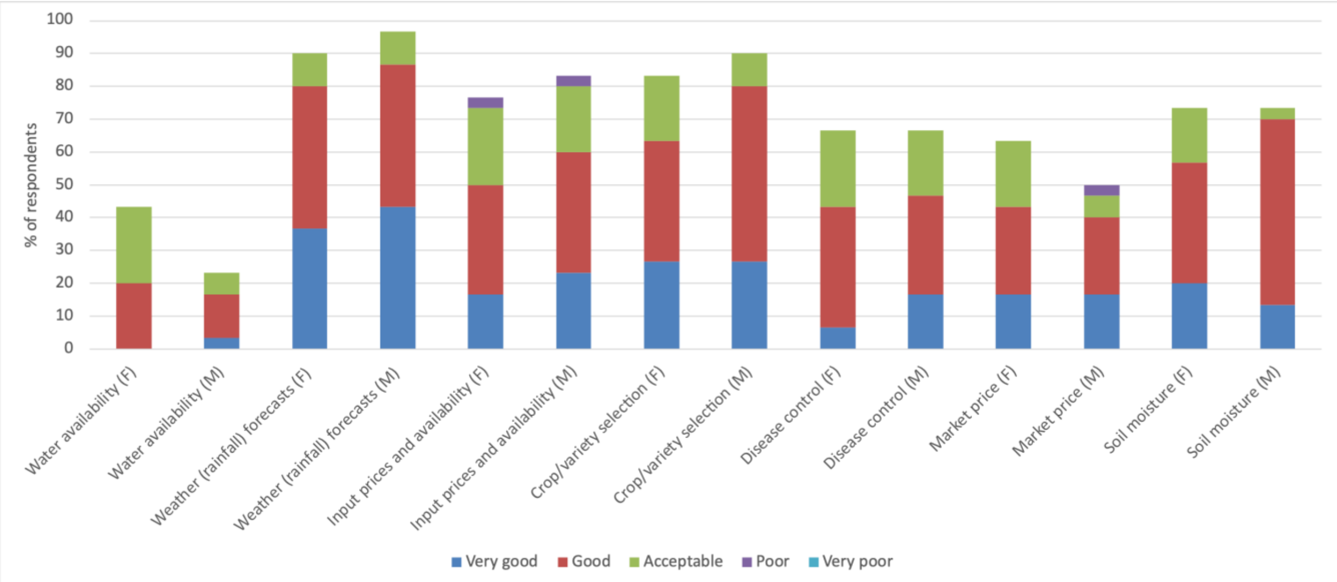

Figure A.V - 1 Quality of information types, as perceived by respondents.

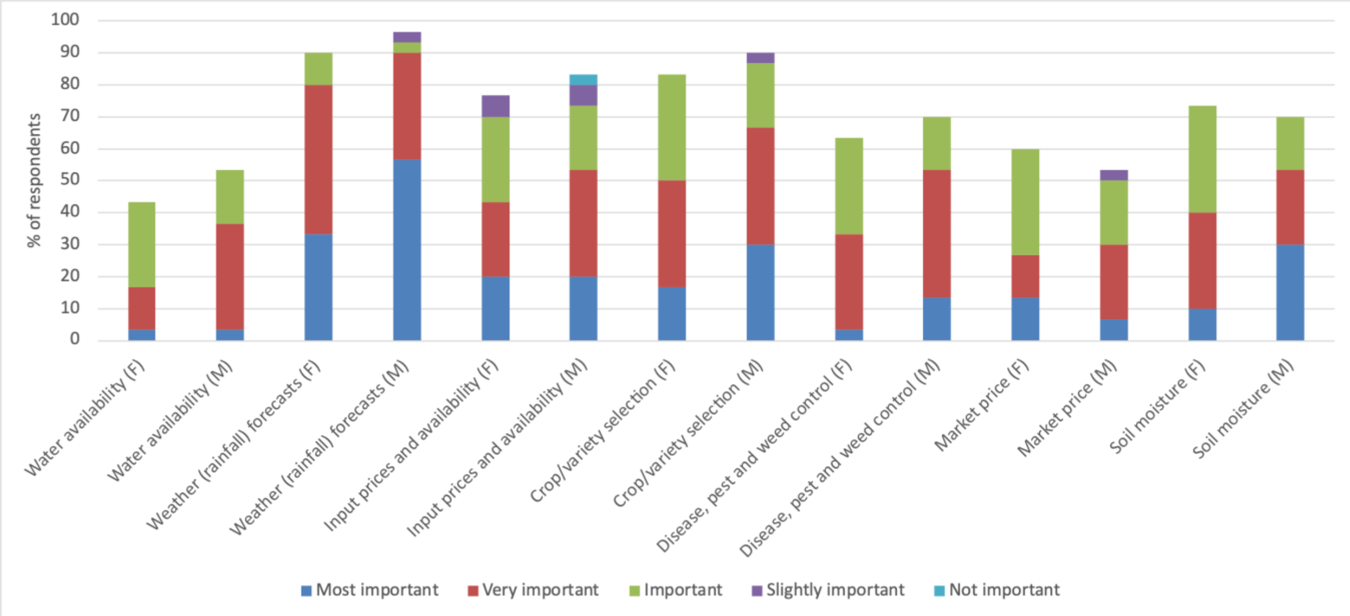

Figure A.V - 2 Significance of information types, as perceived by respondents.

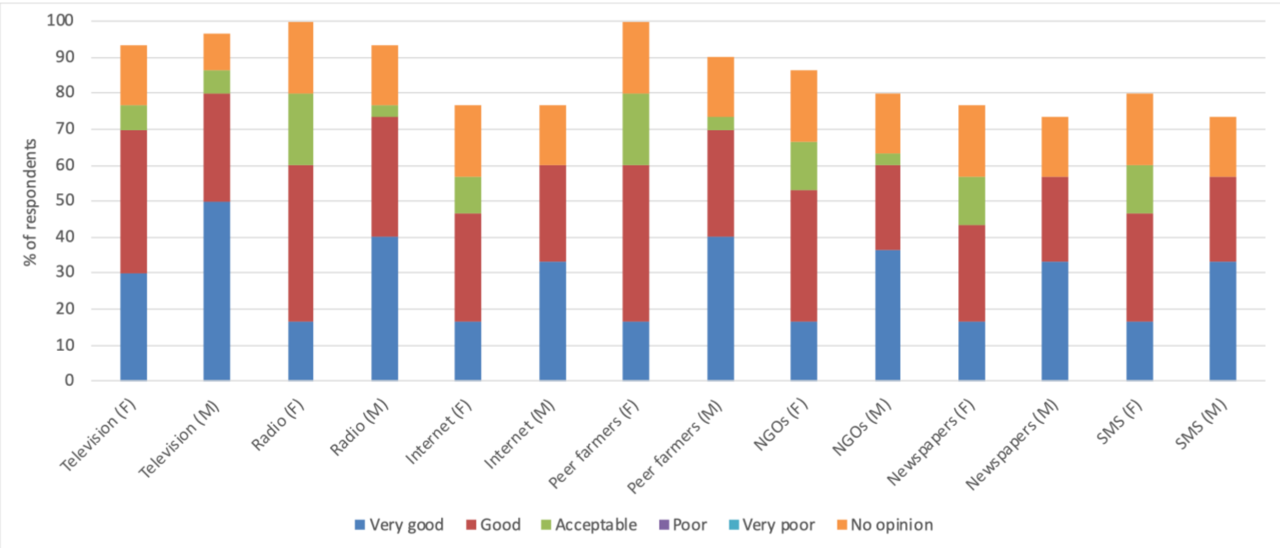

Figure A.V - 3 Quality of information sources, as perceived by respondents.

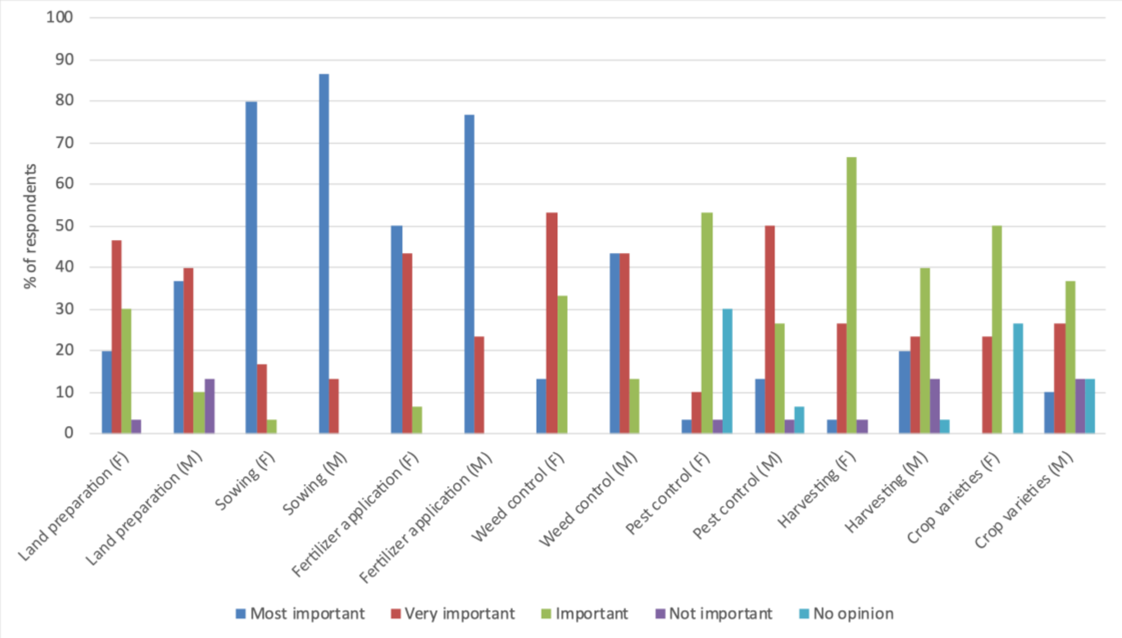

Figure A.V - 4 Significance of soil moisture information for different farming stages, as perceived by respondents.

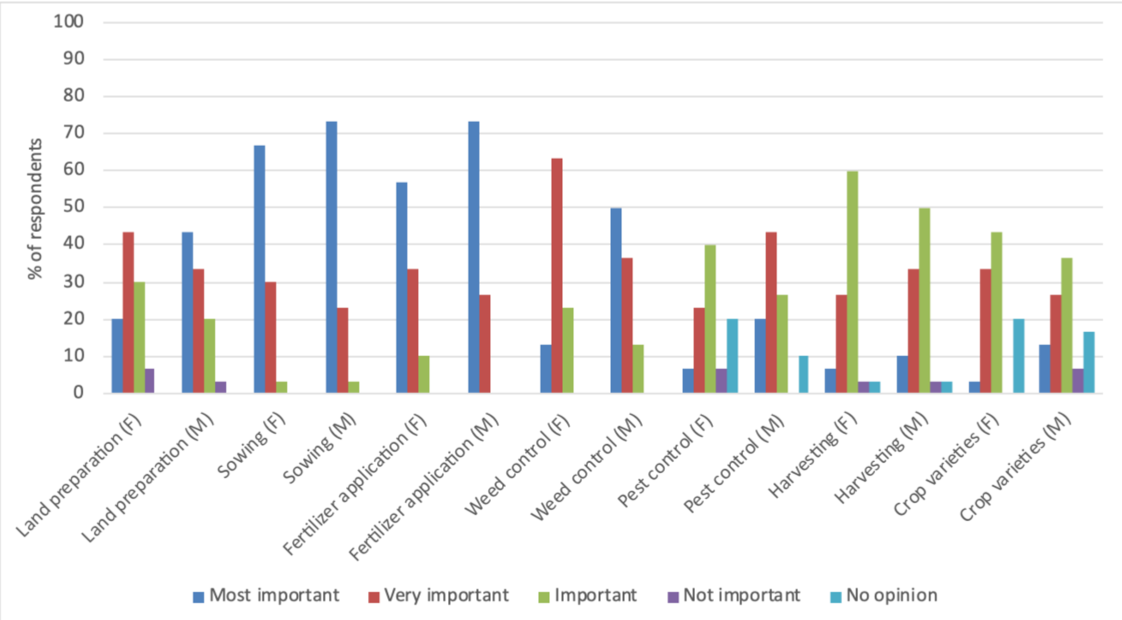

Figure A.V - 5 Significance of rainfall information for different farming stages, as perceived by respondents.

V.C – Rainfall Indicators

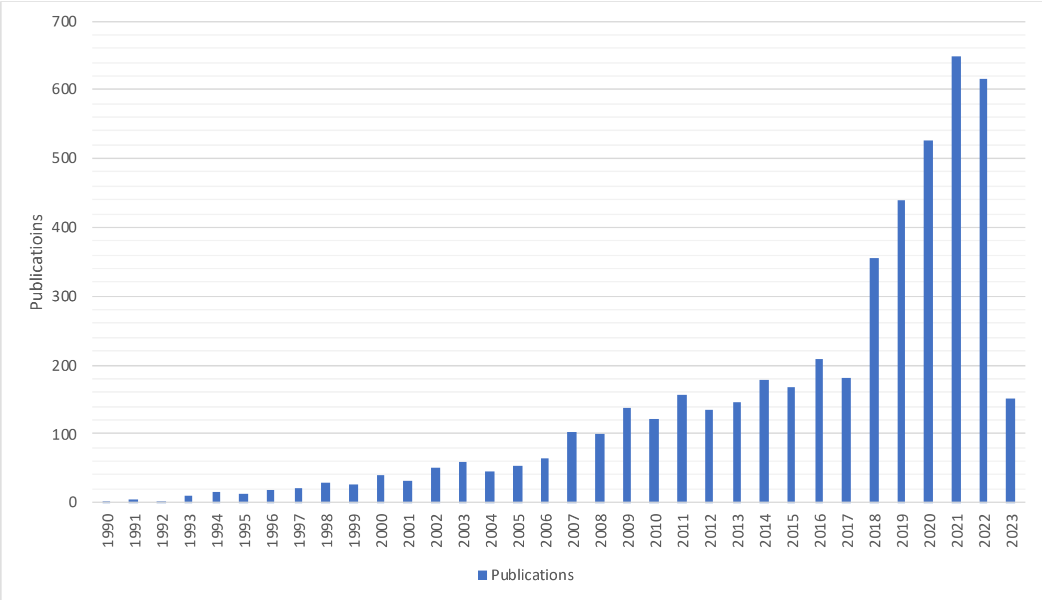

Figure A.V - 6 The number of papers published on indigenous knowledge, from 1900 to 2023 (4th of May). Based on Malapane et al. (2022).

The paragraph below provides the reasoning behind the classification of the local rainfall indicators found in the baseline study into spatial scales based on the results of the literature review. The numbering of the indicators in the list below corresponds to the numbers of the indicators in Table 7.

2. Ants as an indicator of no rain is also used in Ethiopia (Ayal et al., 2015). Furthermore, Gyampoh et al. (2011) mention that ants moving from higher areas to lower areas (near streams) in the Volta region means that little rain and no floods are to be expected. In the Kumbungu district (Northern Ghana), ants carrying their eggs downhill means rainfall cessation in a few days up to a week (Nyadzi et al., 2021). Therefore, this indicator is classified as a regional indicator.
3. The direction of the bat nest opening as an indicator for rainfall has not been documented in the articles included in the literature review and is therefore classified as a local indicator.
4. Birds (maliga or saa(chir)) chirping as an indication of rain in 0 – 1 day is reported by farmers in the baseline study. The chirping or singing of birds as an indicator of rainfall is a widely used indicator around the globe. However, the chirping of the maliga or saa bird is not documented elsewhere and is therefore classified as a local indicator.
5. In the three communities, a bird laying its eggs is an indication that it will not rain for a while. In the Miyar Valley in India, when the lapwing lays its eggs on the bare ground, it is an indication of less rainfall or drought. When the lapwing lays its eggs on an elevated part of the field, it indicates intense rainfall in the coming monsoon (Padigala, 2015). In the Singida Region in Tanzania, the Kokoo carrying its eggs is an indicator of a short rainy season (Mahoo et al., 2015). On the other hand, in Nigeria, if the guinea fowl lays its eggs, it is said that this predicts the onset of rain (Oluwasemire et al., 2012). As the farmers in the study did not specify the laying of eggs of which specific bird is an indication of no rain, we cannot say whether the signal corresponds to the beforementioned signals, and therefore the indicator is classified as local.
6. In the three communities researched in this study, clouds are used as an indication that it will rain soon. The use of clouds as an indicator for rainfall is a globally applied indicator. For example, it is also used in Kerala, India (Anju & Bonny, 2019).

7. Two participants reported the sound of clouds as an indicator of rain within 24 hours. Whereas in literature the sound of clouds is not documented as an indicator, the sound of thunder and the sound of wind are mentioned. The sound of thunder in Kerala, India, indicates the onset of the N-E monsoon (Anju and Bonny, 2019). In the Southern province of Zambia, hearing the wind means either rain in 3-4 days or that there will be good rain (Kanno et al., 2013). Nevertheless, as the signals are not exactly the same, the sound of clouds is classified as a local indicator.
8. Odd days are a local indicator for rainfall, as it is not reported in the literature so far.
9. According to the participants, dew in the morning indicates rain in 0 – 2 days. In the Sesheke district in Zambia, and in Zimbabwe and South Africa, the absence of dew is also an indicator for potential rains on the day (Mushimbei & Libanda, 2022; Tanyanyiwa, 2018; Basdew et al., 2017). The indicator is therefore classified as regional. Conversely, in the Rwenzori region of Uganda and the Chibuto and Guija districts in Mozambique, the absence of dew is used as an indicator for the cessation of rain or drought (Nkuba et al., 2020; Salite, 2019).
10. In the Greater Accra region of Ghana, when there is a lot of dew falling from midnight to the following morning, this indicates no rain is expected the next day (Gbangou et al., 2020). However, in this study, when dew is observed around dusk, it means rain in 3 – 4 days. As the outcome does not correspond, the use of dew around dusk is classified as a local indicator.
11. Ducks swimming on dry soil indicates rain within 0 – 2 days. This is a regional indicator. The indicator is, for example, also observed in the Zabzugu-Tatale district in the Northern Region of Ghana (Gyampoh et al, 2011), and the Delta State in Nigeria (Fitchett and Ebhuoma, 2018). In the Tanga region in Tanzania, it predicts the onset of rains (Mahoo et al., 2015).
12. The observation of earthworms on dry soil in the daytime indicates rainfall within a few hours - 3 days. This indicator is also reported in the Kumbungu district, located in the Northern Region Ghana (Nyadzi et al., 2021). Therefore, it is classified as a local indicator.
13. Activity of fish in the river is a local indicator for rainfall. Fish is used as indicator in other countries in Africa, but with a different signal.
14. Fog as an indicator for rain in 0 – 2 days is a regional indicator, because it is also reported in Kumbungu district, Northern Ghana (Nyadzi et al., 2021) and Rwenzori region in Uganda (Nkuba et al., 2020). In other regions, fog usually means that no rain is expected.
15. The croaking of frogs is documented in both Asia (Varah & Varah, 2022) and Africa (e.g., Baffour-Ata et al., 2021) as an indicator of rainfall approaching. Therefore, it is a global indicator.
16. One participant reported that when you hear frogs croaking and you observe high temperatures, this is an indicator that it will rain soon. This specific combination is not reported elsewhere and is therefore classified as local.
17. The moon is a common indicator used for predicting local weather conditions. The specific observation of a ring around the moon indicates that it will rain within 0 to 3 days. This specific moon indicator is also used in the Greater Accra Region of Ghana (Gbangou et al., 2020), Botswana (Mogotsi et al., 2011), South Africa (Ubisi et al., 2020), Tanzania (Elia et al., 2014), Zimbabwe (Tanyanyiwa, 2018; Shoko & Shoko, 2013) but also in India (e.g., Shankar et al., 2008; Anju & Bonny, 2019) and Mexico (Camacho-Villa et al., 2021). Therefore, it is a global indicator.
18. A ring around the moon in the dry season indicates rainfall during the night, according to one participant of the baseline study. This specific timing of the signal is not documented so far, and the indicator is therefore classified as local.
19. When the insect Saa paga is flying around, it means rain within the day. The observation of this insect is not reported elsewhere, and therefore it is here classified as a local indicator of rainfall.

20. In the early days (14 days) of the new moon, it is difficult to predict the weather. The new moon is a local indicator.
21. Mosquitos as indicator for rainfall is also reported in the West Mamprusi District and Kumbungu District of the Northern Region (Gyampoh et al., 2011; Nyadzi et al., 2021) and Zimbabwe (Alvera, 2013), but also in Mexico (Rivero-Romero et al., 2016). It therefore is a global indicator.
22. The neem tree is also used as an indicator in India and Uganda. However, the signal of the neem tree fruiting for the 2nd time as an indication of the start of the rainy season is not reported in these regions, and therefore the signals are different. Thus, we classify this indicator as local.
23. When the respondents observe no stars, it indicates rain within 24 hours. The absence of stars is not reported in other studies, but in Zimbabwe they do report that when you observe only few stars, it indicates rain falling soon. Still, we classify this indicator as local.
24. No noise indicates rain in 1 – 2 days. This is a local indicator, as it is not reported elsewhere.
26. Snails crawling on leaves/trees is a local indicator. In the Tanga Region in Tanzania, snails are also used as an indicator, but with a different signal and outcome.
27. Stars 'swimming' in water is a local indicator because it is not reported elsewhere.
28. Stars appearing divided in the sky is a local indicator because it is not reported elsewhere.
29. The halo around the sun is also an indicator used in Kumbungu District (Nyadzi et al., 2021), and Greater Accra region (Gbangou et al., 2020), Zimbabwe (Tanyanyiwa, 2018; Shoko and Shoko, 2013). Therefore, it is a regional indicator.
30. Flowering of trees is a common indicator used to predict the onset of the rainy season (Snoeren, 2020). However, using the cotton tree has not been reported. Therefore, it is classified as local.
31. Strong wind as an indicator for (absence of) rainfall is used in many areas. However, in some regions strong wind indicates drought, and in others it indicates rain (e.g., in Mahoo et al., 2015). It is only used in countries in Sub-Saharan Africa to predict rainfall (and not absence thereof), thus it is classified as regional.
33. In Mozambique windless conditions mean drought (Salite, 2019), but in the communities that are part of this study, one person indicates it predicts rain. Therefore, it is classified as a local indicator.
34. Observation of a yellow cloud is a local indicator, as it is not reported elsewhere.

V.D – Skill Assessment

Table A.V - 3 Background information of the skill assessment data.

	Women	Men
Number of respondents	12	27
Number of forecasts total	53	225
Number of days for which the probability of rain (POR) is calculated	36	65

V.E – Perception of Local and Scientific Forecasts

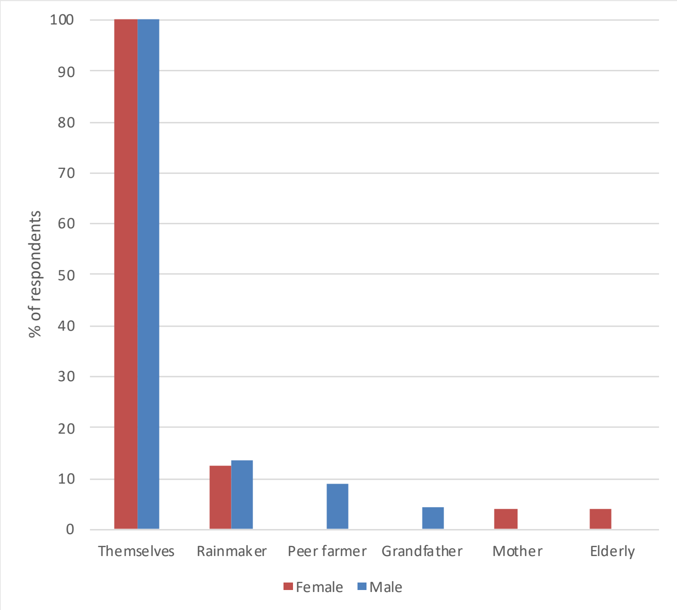

Figure A.V - 7 The makers of the local forecasts that the respondents use.

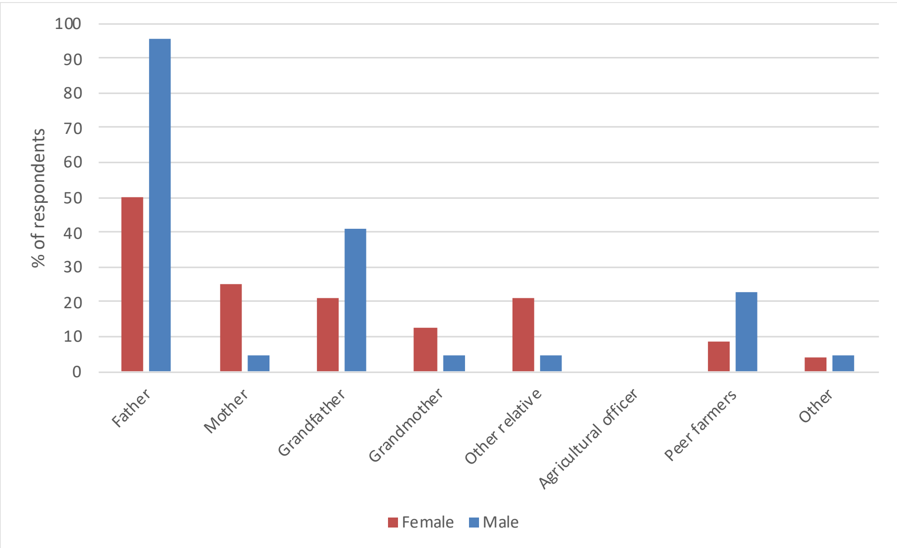

Figure A.V - 8 Teachers of indigenous knowledge for forecasting.

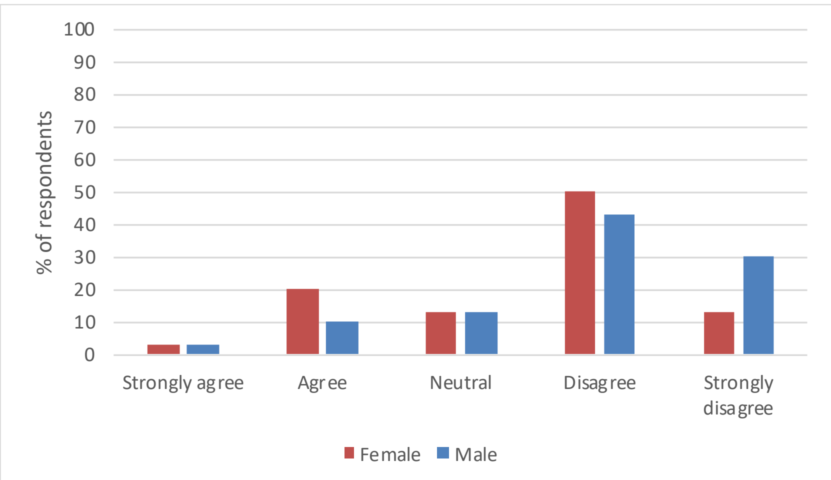

Figure A.V - 9 Statement: I prefer to use local forecasts over scientific forecasts.

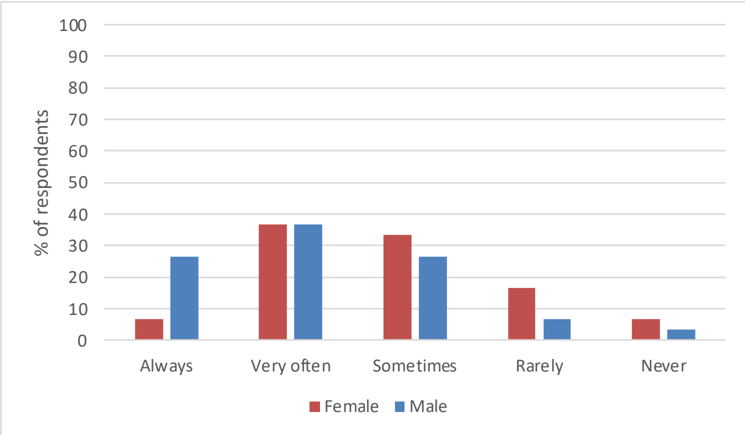

Figure A.V - 10 Integrated forecast use of respondents.

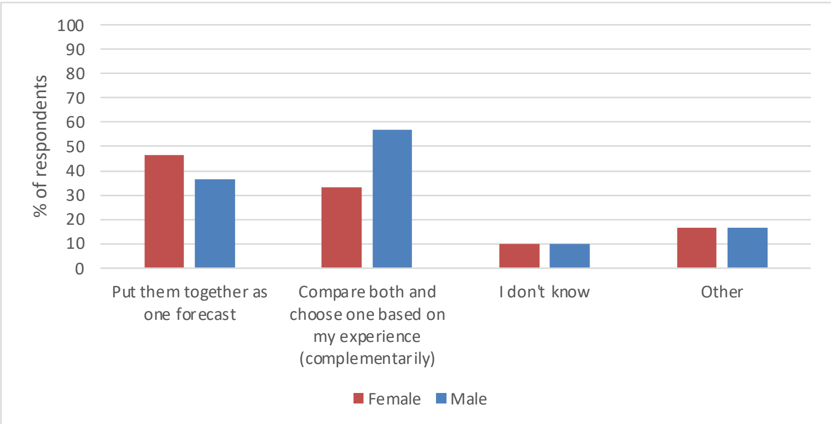

Figure A.V - 11 Methods for integrating local and scientific forecasts, as done by the respondents.

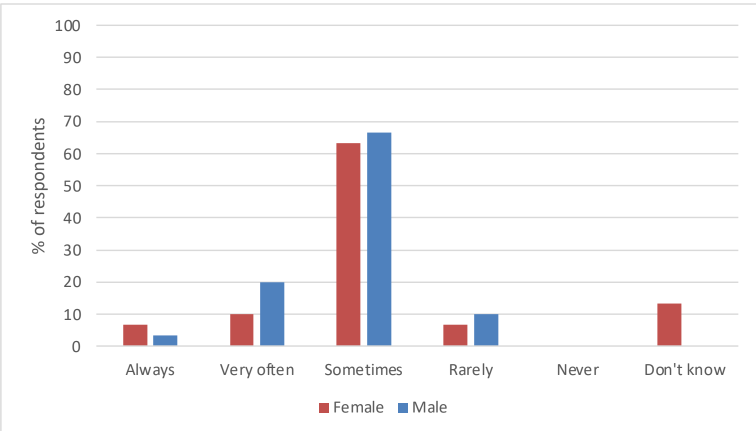

Figure A.V - 12 Alignment of the local and scientific forecasts, as perceived by the respondents.

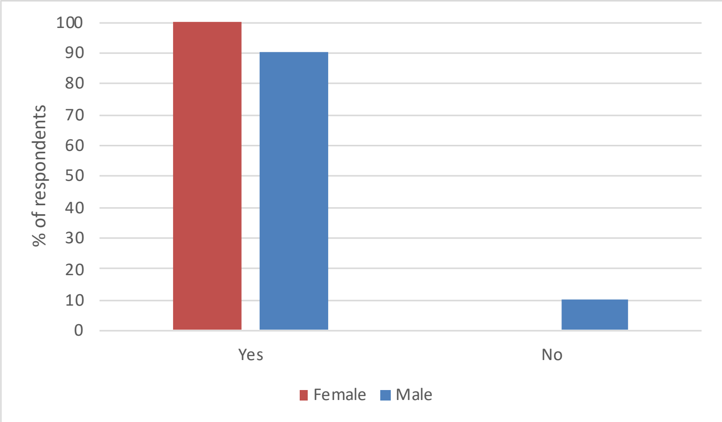

Figure A.V - 13 Respondents' preference for an integrated forecast over two separate forecasts.

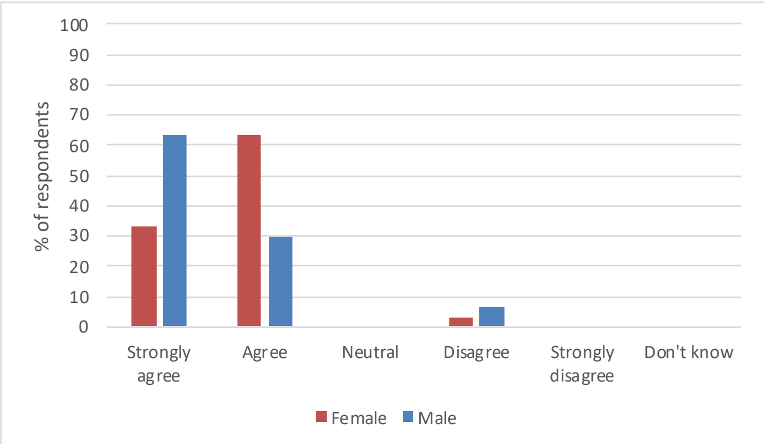

Figure A.V - 14 Statement: I will accept the information from an integrated forecast more because it combines the best of scientific and local forecasts.

Appendix VI – Endline Study Results

This Appendix provides additional information on the results from the endline study, presented in Chapter 4.6.2.

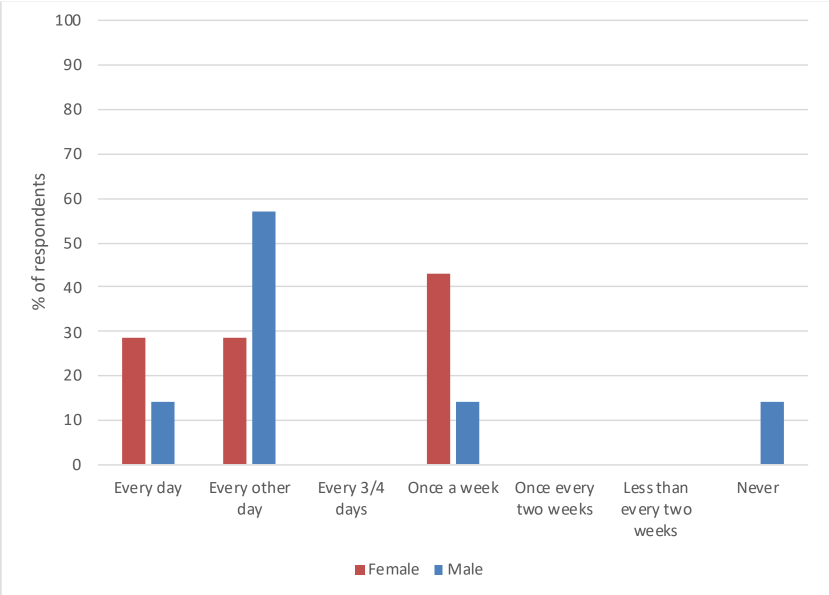

Figure A.VI - 1 Frequency with which the endline respondents check the scientific forecast in the DROP app.

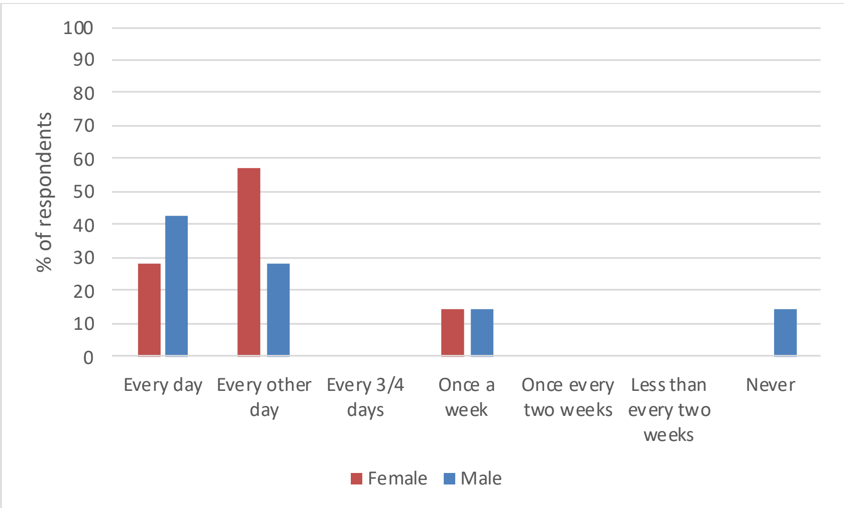

Figure A.VI - 2 Frequency with which the endline respondents check the local forecast in the DROP app.

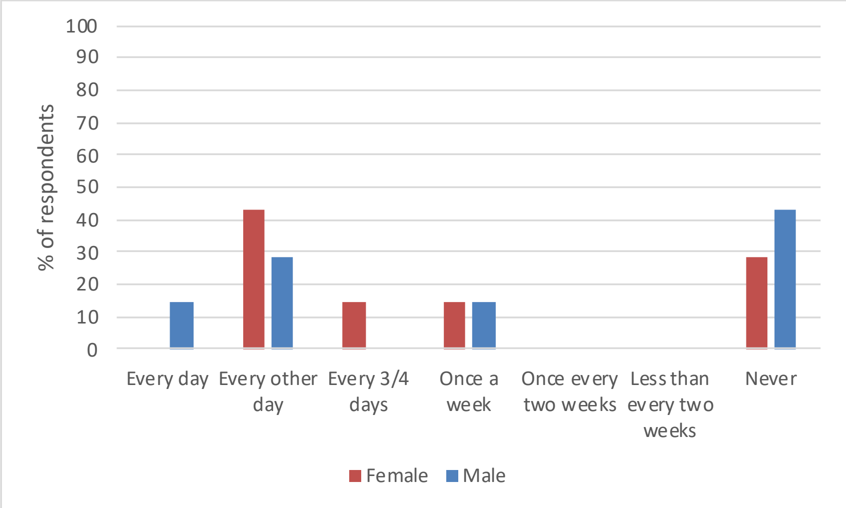

Figure A.VI - 3 Frequency with which the endline respondents check the soil moisture forecast in the DROP app.

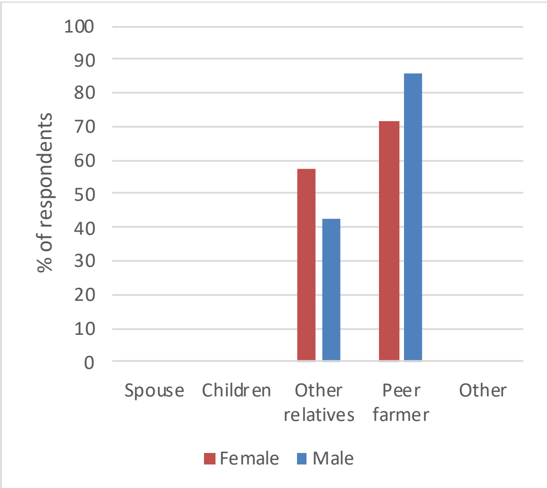

Figure A.VI - 4 People with whom endline respondents share the local and scientific rainfall forecasts from the DROP app.

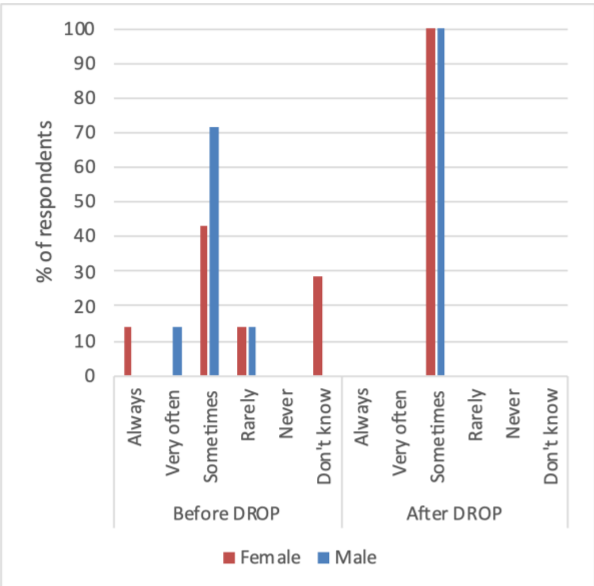

Figure A.VI - 5 Alignment of the local and scientific forecast, as perceived by the endline respondents.

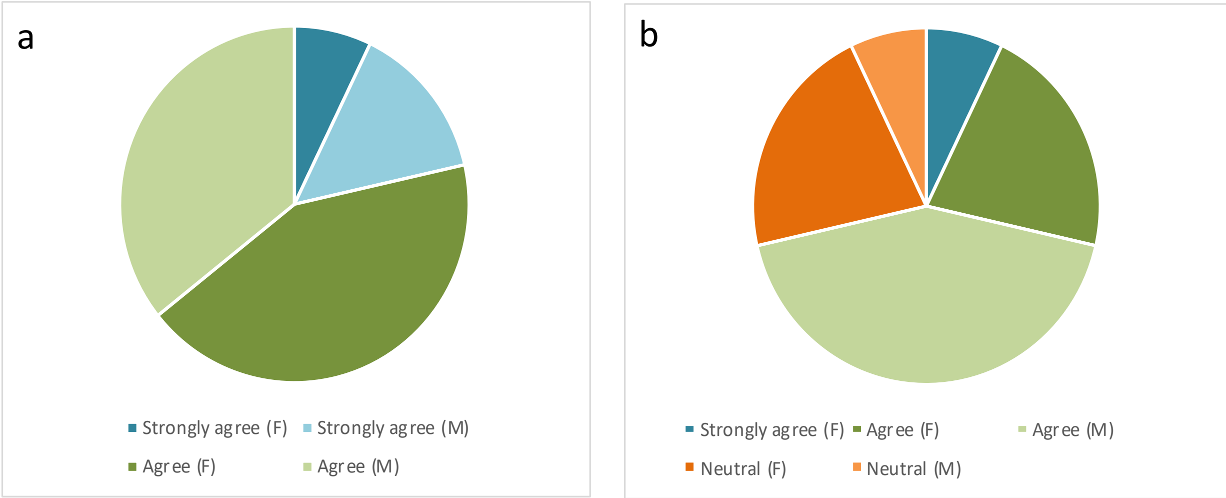

Figure A.VI - 6 Statement: After using the DROP app, I trust the scientific forecast (a) and local forecast (b) better.

Appendix VII – FGD Notes

This Appendix contains the leading questions used during the FGDs and the notes taking during the FGDs.

VII.A – FGD Leading Questions

1. Do you **have access/receive agricultural information** that helps you in your farming decision-making?
    a. If yes, what information do you receive and from what source?
        i. Do you receive information on soil moisture and rainfall?
2. **How important is that information (and for what practices)? And how reliable do you think it is?** Does it meet your needs?
3. In general, what do you think the **issues with scientific forecast**s are?
4. What kind **of information do you need to make agricultural decisions**?
5. Do you use **local forecasting**?
6. What are **indicators** that you use often and what do they mean?
7. Are these forecasts often correct/how **reliable** do you think they are?
8. Are **the indigenous and scientific forecasts** often the same/**aligned**?
9. What do you think about a **hybrid forecast** (by integrating the indigenous and scientific forecast)?
10. What do you expect the **socio-economic impact of such a hybrid forecast** to be?

VII.B – Nabogu Women

1. The farmers don't receive any agricultural information from any source, apart from themselves. But they do receive rainfall information.
    a. The knowledge of agriculture the farmers have themselves: time of sowing. They always wait 3 – 4 rains before they start sowing.
    b. They used to grow the groundnut first, then maize, then rice, then soybeans (in order of sowing date). But due to new technologies/information, they just farm and don't follow that order.
    c. The length of the rainy season is changing. The farmers cannot say anymore how long the season is, or when the onset of the rainy season is.
    d. They receive soil moisture information from each other/peer farmers (neighbouring farmers/someone that comes from the field; that farmer can say "ooh I saw that there was moisture in your field").
    e. They do receive rainfall information, from television and SMS.
        i. They also receive humidity information from the meteorology services: when they are broadcasting the rainfall, sometimes they also add the humidity in their broadcast.
2. They use this information for land preparation, ploughing and sowing. Ploughing: some use a hoe or a drought animal (ox, bull) to pull the plough; some use tractors (becoming most common).
    a. Reliability: SMS = 30%, TV = 45%
3. Time of sowing of which crop: when to sow the groundnut, when to sow the maize, etc; and also, which variety they should sow.
4. Accuracy: it's not accurate enough.
    a. The issue with the scientific forecast is that they can't always follow it because of a lack of resources; because the lead time is not sufficient. When they get the information, they are not always prepared for it. If the information says that they need to do something next month/two weeks, they are not ready to follow up on the advice. Because they don't receive the information in time. So, then they have to

follow what they already know. They would like to follow it, but they can't, because they don't have the resources.

    i. The timing of sowing is always good for wealthy farmers, because they are ready to start at any time.

5. Yes
6. Ants, frogs, earthworms, ducks.
    a. When the ants are carrying their eggs from one particular place to the other, and also the distance they carry the egg, says something about when it will rain. When the ants carry their eggs to a hole/trench to a hill, it will rain. But when they carry their eggs from a hill to a hole, the rain is far away (not close by). It depends on the distance the ants are travelling; the shorter the distance the ants travel, the closer by the rain.
    b. When you observe a frog croaking during the daytime, it means rain is coming (normally they croak at night).
    c. If during the daytime you don't see any moisture around the earthworms (so it is dry around the earthworms), then it signals it might rain.
    d. Ducks. When you see a duck playing with their feathers, acting like it is swimming on the dry soil (flapping the feathers as if it is swimming), then it means rain.
7. 50% reliability
8. Farmers are saying that the forecasts are not aligned. And the accuracies are not the same. The scientific forecast will tell them the time of rainfall, but the local forecast does not.
9. It will help them a lot with their farm practices (the ones they identified earlier; sowing etc.).
10. It will help them to manage their activities. Also in the household: cooking or drying their farm produce; managing their time and resources in general. Because they don't want to be outside when it rains. It can help in their businesses/on the market; they don't trade when it rains.

VII.C – Nabogu Men

1. The Ministry of Agriculture has a TV program on prime TV, every Sunday. In this program, they tell you which seeds to use and when, and when the season starts and ends. The farmers also receive weather information via TV and radio.
    a. At first, the farmers didn't really believe in the information they received from TV/radio, but with time they started to trust it because the information was correct. When they say it will rain, it did.
        i. They only receive rainfall information, not soil moisture. But they do receive info on when the soil is wet, you should do this and that.
2. One man says the information is very important. Fertilizer washes away when it rains. But you also need a bit of rain for it to work. They also hire people to harvest, but when it starts to rain the people don't harvest and the money is lost.
    a. Percentage reliability: they do trust it but not completely, 75% is their estimation of the reliability.
3. Sometimes the seeds they buy are of bad quality. They want to know where to buy good seeds/how can they know which seeds are okay. Fertilizer also comes from many different companies, but they don't always know from which company. And sometimes the fertilizer of companies gets mixed. Some companies have better fertilizer. Sometimes they buy fertilizer, and the fertilizer doesn't do anything. They also struggle with genetically modified crops. The seeds they buy in Tamale do well, but if they use the seedlings of those crops grown, then they don't germinate.
4. Accuracy and timing are issues. Sometimes they think rain is coming and then they prepare to sow or fertilize, but then it doesn't rain. And then they lose their resources. And often the predicted start of the rainy season is wrong.
5. They use local forecasts a lot. Some people know it and teach the rest when the signal happens.

6. If you wake up in the morning and you feel a lot of heat in your body, it will rain that day. If the wind is coming from west to east, then it will rain that day/night. They also look at the stars and the moon. Depending on the distance of the ring around the moon, it will rain sooner or later. Also, the ants carrying their eggs is an indicator. Some farmers in the village have a lot of knowledge of the indicators and share it with their peer farmers. That's how the local forecast is shared.
7. The timing with the local forecast is difficult. Percentage reliability: 40%
8. The alignment between SF and IF is low because the timing of the forecasts is different.
9. They are all enthusiastic about a hybrid forecast. Especially if the knowledge of other villages is also incorporated.
10. It is very important to them. Money can be saved.

The farmers are curious to know our training and how it will work.

VII.D – Gushie Women

1. The female farmers at Gushie receive agricultural information that help them in farming decisions.
    a. The information received is as follows: 1) time of sowing advised by the agriculture extension agents that they received through peers, but they often can't follow such information because they don't have the resources to do exactly as they (agents) do; 2) buying of farm inputs. They inquire about this from their male counterparts (especially their husbands/brothers) as to which type of fertilizer or chemicals to buy; 3) weed control. They received information on how to control weeds on their farms and why it is necessary or the role it plays in terms of a good yield. They received such information from sources such as radio, television, peer farmers and SMS (through MTN & Vodafone).
    b. They received soil moisture information from peers whose farms are closer to each other, and rainfall forecasts from other sources.
2. Such information helps them in sowing, harvesting and weed control and the reliability of the information received is perceived to be 80%.
3. The extra/other information needed by the participants to make agricultural decisions is: 1) knowledge on how to apply fertilizers and spray chemicals, particularly the dosage; 2) knowledge on which type of fertilizer and chemicals to buy; 3) providing more information on general farm management; 4) variety selection (high yielding seeds); and 5) onset and cessation of rainfall. Note: they need access to 1, 2, and 3 themselves so that they won't have to ask their husbands or brothers for information (as this could lead to misunderstandings).
4. The issue with the scientific forecast as mentioned by the participants is the accuracy of the rainfall predictions. This can sometimes waste time and resources when the predicted event doesn't occur.
5. Yes, they know some of the local forecast indicators of rainfall and they do use them for farming decisions during the growing season.
6. Some of the indicators mentioned by them are:
    a. Temperature – High temperature caused by either scorchy sun or not during any time of the day within the rainy season.
    b. Wind direction – Wind blowing from east to west is an indication of rainfall in the rainy season.
    c. Dew – Now dew observed early in the morning during the rainy season is a sign of rain.
    d. Fog – Fog early in the morning or during dusk
7. The reliability of the local forecast as perceived by the female farmers is 60%. They have trust in it also because it is their own knowledge (that they have when growing up). However, they

lack such knowledge because they are often not close to people whom they could have learned it from better.

8. According to the participants, the local and scientific forecast is not often but sometimes aligned. The scientific forecast they heard from the sources and what they observe themselves sometimes occur to be the same.
9. They think the hybrid forecast will be the best by improving the quality and reliability of forecasting rainfall.
10. It can help improve their yields. By doing so, according to the participants, they will have more produce for food and extra to sell for their children's school fees and with the trading businesses in the markets.

VII.E – Gushie Men

1. The farmers have never had a visit from the Ministry of Agriculture for training, but they can listen to their advice via the radio or tv (when to sow, what plants need etc.; onset of rainy season). The info does not include rainfall or soil moisture information.
2. One person uses the TV when he wants to sow or fertilize. But no rainfall or SM info. Only one person in the group has a TV. There is one person who has a bit more knowledge of rainfall and receives some information on TV, and he trusts it. They learned from TV that they have to be careful close to the river and that you should not plant crops close to the river as they can get flooded.
3. One person said they want to know which crops to plant at the beginning of the season, but the other participants did know this. There is one TV program that gives information on animal husbandry, but not everyone has access to it. They think that the district manager of the Ministry of Agriculture visits too little. They don't even know who it is.
4. They don't really receive scientific forecasts. Most have no idea what the reliability is. One person estimates the reliability at 70% (the person that also has the tv).
5. They would like to receive the scientific forecast.
6. They learned indigenous knowledge from their parents. An example is to expect rain on odd-numbered days. If the early sun is strong and there is a lot of heat, then you can expect rain (probably the same day; but this only works at the beginning of the rainy season). A high temperature in the morning is an indication of rain. The low temperature in the morning is an indication of no rain.
    a. 45 to 60% reliability (local forecast)
    b. One person uses the local and scientific forecast together, and that works very well for him.
7. We hear many sounds of approval: they would love it. It helps them decide. If it works, they will lose fewer seeds (they lose seeds when the SM is not good). When there is a dry spell within the dry season, they would like to know it beforehand so that they can wait with planting, so that the crops don't die, and for knowing when to sow and plant.
    a. They use plants and grasses to determine the start of the rainy season. Like the neem tree (the second ripening of the tree means that the season starts soon). Then they start to sow the groundnuts; because then the rainfall is still moderate, and the soil is not too wet.
8. It will especially impact the younger generations, as they are not taught this in school. They will try to spread it over the communities, and then to other communities etc. Currently, there are only 1 to 2 people that receive scientific forecast, and then they share it with peer farmers during serious meetings and with their neighbours.

Note: all land is the property of the chief, and people can borrow it from him.

VII.F – Diare Women

1. Radio, tv, peer farmers

        a. General farm management (how to fertilize, plough, sow, weed control)
        b. Time of sowing
    - Challenges: they don't have the resources to follow the advice. Sometimes they need more time to prepare, and then it's too late to follow the advice.
    - They also receive SM and rainfall info. SM: mostly from experienced farmers, but not from radio or TV. They also see rainfall as SM, as with rain comes SM.
    - They receive rainfall information from TV/radio.
2. Rainfall information can help with when to sow. The order of sowing is different from the men's. The women first sow groundnut. They have two varieties. The 1st is china, which is sown first, then the 2nd, which is called abain. Then they sow rice and maize at the same time. Then they sow soybeans.
    a. The women say that the information meets their needs. When they receive the information and can follow it, they see that their crops do good. They also see a difference in who follows the advice and who doesn't.
    b. Reliability is around 30%. They receive it about once a week, but they don't always have time to listen to it.
3. (Note: it took a long time for them to answer this question, some don't say anything). Farm equipment availability; where to get the equipment. (Note: it seems as if they overheard the men say this, so the answer seems biased).
4. Sometimes it is incorrect. But they believe in it, and then it is not true. It is not location specific.
5. Yes.
6.
    a. Wind: from east to west
    b. The heat
    c. They have less indigenous knowledge than men because they are not close to the men & elderly, so it is difficult for them to acquire the knowledge.
7. 10%. They don't have much knowledge of it.
8. Sometimes aligned, according to the women.
9. Will be good because they have seen that the scientific forecast has higher accuracy, but they cannot neglect the local forecast. Therefore, a hybrid forecast is best because it minimizes losses.
10. To change their daily activities: drying farm produce, cooking, fertilizer application, spraying chemicals (they can postpone when they know it will rain).

Overall note: the women gave much less input than the men. Some were very quiet, and they also seemed less interested.

VII.G – Diare Men

1. Yes, from e.g., radio, TV, peer farmers and agricultural extension agents.
    a. Time of sowing/planting
        i. They also learn this from their forefathers/peer farmers. There is a particular order in the crops they sow. First, they sow yam, then plough and sow groundnuts, then rice, then maize, then soybeans.
    b. Crop variety to choose
    c. What seeds to choose for sowing (from TV)
    d. Time to stop sowing a particular crop
    e. How to apply fertilizer
    f. How to deal with weeds
    g. General farm management (see above)
    h. Post-harvest handling: how to store harvest and prevent losses
    i. Soil moisture and rainfall info

All 5 farmers receive this.

2. For farm practices like sowing, the right timing of sowing information is very helpful to them, because it prevents losses. One challenge with the TV info is that they use a planting machine to plant (on tv), so the farmers then cannot follow the advice because they don't have the machine. The information they receive is difficult to follow because they don't have the right resources to follow up on the advice. If the source says to fertilize in 3 weeks, then sometimes they cannot always buy the fertilizer in time.
    a. It meets their needs partially, but they can't always follow the advice. Even when they follow the advice completely, their yield is not as good as promised/it should be.
    b. They give the information they receive a score of 80% reliability.
3. They would like to have a combined harvester. But they don't know where to get it. This results in losses over harvesting. They would like information on fertilization: the nutrients in their fields are depleting. They need to know where to get fertilizer and for what price. They need pest and weed control info. Sometimes the information sources give a certain product name, but they don't know the product name or where to get it. They would also like to know where to get a tractor for sowing.
4. It is not location specific. They just give info for the entire Northern Region. Sometimes farmers are waiting for the rain to happen, but it doesn't come, but then it does rain in Savelugu for example. And sometimes the info gives the duration of the rainy season, and then farmers will choose a crop variety that will last that long. But then when the rain stops early, the yield is wasted. However, the farmers say this wrong prediction does not happen often.
5. Yes.
6. Indicators:
    a. Ants: the distance shows how close the rain is.
    b. Winds: some winds are like a tiny cyclone. If they observe that 3x during that day; then it will rain within the day.
    c. Earthworms: when you see them in the daytime, and they come out of their habitat on their own, you know it will rain. If they are disturbed by other animals and come out of their habitat because of that, it doesn't mean rain.
    d. The warmth/heat they feel in their bodies. From 3 pm onwards: it means rain.
    e. When it is a full moon with a ring around it and it is yellow: then that day it will be sunny. But if the ring is dark, it means rain.
7. Reliability: they also rely on the local forecast. Reliability is 90%.
8. The forecasts are often aligned. Sometimes they know the weather sooner because of the local forecast, and when they receive the scientific forecast, the forecasts turn out to be the same.
9. The hybrid forecast will be the best for them. The scientific forecast can give a longer lead time. While they do really trust the LF, the lead time is shorter. The combination is good.
10. It will help them with the timing of when to do specific farm activities, which leads to more yield. This in turn benefits the whole community.

Appendix VIII – Notes Field Visit Gbulung

During the field visit to Gbulung, we first did a question and feedback round with the farmers. During this session, farmers suggested that the DROP app should have an hourly or 3-hourly forecast. This will allow farmers to go back to the field if it will not rain on short notice. Furthermore, they suggest adding humidity and temperature to the app, and perhaps acid rain. Staff from the University of Development Studies in Tamale tell the community members of Gbulung that they will arrange adult education for them, to make data entry easier. This is necessary because many farmers are struggling with entering their observations themselves.

During the training, we observed that the farmers seem to remember how the app works pretty well. However, not everyone understands whether to choose to sign in or register when starting up, because not everyone can read English.

After training, we asked the farmers whether they think that the DROP app has been beneficial to them. They respond that they have used the app for:

- Fertilizer application
- Spraying herbicides
- Sowing
- Weeding
- Harvesting
- Drying farm produce (groundnuts, okra, pepper) (this is reported by women because this is a chore done by women)

All farmers acknowledge that they have benefitted from the app. They also mention that they use the information from the DROP app for other daily activities like cooking, travelling, trading, and in general knowing when to hurry up for going outside. They don’t want to be outside when it’s raining, and no one will be on the market anyway.

Appendix IX – Fieldwork Report

This Appendix contains the full fieldwork report, which was written together with Joep Bosdijk and Marin Schadee.

Fieldwork evaluation

Fieldwork planning

On September 2nd, the three of us (Marin, Joep and Jacqueline) flew to Ghana. We arrived in Tamale on Saturday September 3rd. On September 6th, we had our first meeting with Jamaldeen, a UDS MPhil student. We thought that Jamaldeen would be our translator. However, during this meeting we learned that he would be busy working on another project. On September 7th, we could finally meet Dr. Bizoola, who had been occupied with other business before. He was accompanied by Richard Dogbey, his assistant lecturer. During this meeting, we discussed our fieldwork plans. Previously, Dr. Bizoola had not been aware of our plans. After the first initial meeting, we had a second meeting to discuss further details. On September 12th, we visited the new communities Nabogu, Gushie, and Diare, and Nakpanzoo, which is one of the "old" communities. We had to meet the chiefs of the communities on this day, to ask for permission to do our questionnaires and trainings in their communities. Furthermore, we met some farmers and some farmer leaders that would help us with our plans.

After meeting the chiefs, we started to plan our departure to the communities. At this point, we were not certain who would be translating for us in the field. Soon both Joep and Jacqueline got ill from malaria. Therefore, Marin made day trips to Gbulung, accompanied by Jamaldeen, and the departure to the new communities was delayed. The departure date was set to 23 September but was later pushed back to 27 September so we could first meet Professor Gordona.

Our initial plan was to have about 9 days for each new community: 1 day for the focus group discussions, 3 to 4 days for the questionnaires and 4 to 5 days for the training. In the end, we did not adhere to this plan due to several delays, including multiple cases of sickness and car troubles.

Fieldwork: what did we do

In the end, Jamaldeen did do all the translation for us. In each new community, we started with doing two focus group discussions (FGD). One with 5 men, and one with 5 women. We separated men and women to make sure that women would be able to and feel free to speak their mind. After the FGDs, we did a baseline questionnaire with each of the 20 participants (10 males, 10 females) in each community. This baseline allowed us to collect socio-economic information on each of the farmers and get a better idea of the agricultural and weather information they are currently receiving. Furthermore, we collected the indigenous indicators they use to predict weather. We conducted the questionnaires using the Kobo Collect app on tablets. Then, we started the training. During the training sessions, we taught the farmers how to use the DROP App. First, we had to give a small training on the basics of using a smartphone. Then we had to teach the farmers to sign in on the DROP App. We taught them how to fill in their own observations, and how to read the indigenous and scientific forecast. Furthermore, we taught Nabogu how to use soil moisture feature of the app. As the farmers were quick to pick up how the app worked, and directly asked us to also teach them the soil moisture part, we decided to do so.

Timeliness

We consulted the farmers and farmers leaders to agree with them on a time on which we would do the training sessions. The farmers had the most say in this. Despite this, we had issues with starting our training sessions on time. Especially in Nabogu, many farmers would be an hour late. Therefore, we could not start our trainings on time. The farmer leader in Gushie was very good in making sure that (most) participants were on time, and therefore we had less troubles with starting our trainings on the right time.

Attendance

There was a big difference in attendance between the three new communities. Attendance in Nabogu and Gushie was highest, with around 16/17 people usually present at the training sessions. In Diare, attendance was low. For example, one of the participants was an important person involved in politics. He did not have time to attend our training. Furthermore, the farmer leader of Diare was not as active in making sure that the farmers attend the meetings.

Male-female interaction

There is a clear difference between the men and women in the communities. The men receive more information and have more agricultural knowledge than the women. Furthermore, the women tend to be less open about their opinions when men are present. This stems from their culture. This also means that women might hesitate to ask questions to the male participants or ask them whether they can use the phone to enter their observations into the DROP app. In Nabogu, the group atmosphere seemed to be really good. Men and women were joking around, and the women were quite vocal, especially the older women. However, there were also some younger women that seemed to be quieter during the trainings. In both Gushie and Diare, the men were also more vocal than the women. There was also less interaction between them.

Communication with farmer leaders

In each community, there was a farmer leader/contact person who contacted the farmers for us. The farmer leader in Gushie was very well at organizing and helped us a lot. The farmer leader in Nabogu was also easy to contact, but due to his work as a headmaster at a school, he could not help us before 2 in the afternoon. Therefore, he was sometimes also late to our trainings. The farmer leader in Diare was an older man who was happy to help us, but he did not do a very good job at making sure the farmers were present at our training.
We had one misunderstanding with the communities Nakpanzoo and Nabogu. We did a community motivation meal with the farmers, but not the entire team from UDS was present for it. After the meal, we heard from Dr. Bizoola that the farmers were not happy about this. They did not understand why the others were not there. Furthermore, the UDS team was also unhappy they were not invited. However, we were not aware that it is common practice that all people involved from UDS are also present during these meals. Moreover, nobody spoke to us about this before or during the meal. In the end, Dr. Bizoola called the communities to explain to them that we were unaware, and to apologize to them.

Performance of Communities/participants

Old communities

It was obvious on first arrival in the three old communities that trainings before were given and what was expected of the participants, though not everyone showed up on time. In general, in all communities all participants were present within half an hour of Jamaldeen and me arriving in the community. Moreover, presence was high. During every training at least 18 people were present, but most of the time, all 20. They had still remembered their groups and sat down with them. They picked up on the matter quickly again and thus needed little recap. Gbulung had 4 recap trainings, Nakpanzoo 3 and Yapalsi 2, of just 1 hour.
The younger man performed best during the training, followed by the younger women. The older men and women performed equally *bad*. It seemed that education level (and therefore literacy level) played a big part in this differentiation.

New Communities

Men vs woman and young vs old

There was a clear difference observable between men and woman of different ages. In general, young men performed the best, they were the group with the most experience in smartphone usage, and in general seemed to pick up the information the quickest. Between young men, it was clear that previous smartphone usage and a higher level of education both improved understanding. Young women were also in general still quite quick at picking up the information. The difference between men and woman can probably be accounted for by less previous smartphone use, lower level of education and less use of weather forecasts in general.

Old men and woman were slower in picking up the information and there was no clear difference between men and woman observed.

Community differences

The Communities ranked from best to worst performance:

- Nabogu
- Gushie
- Diare

Nabogu was the best performing community due to their high attendance, good man-woman interaction, eagerness to learn and attendance of mostly young and middle-aged participants.

Gushie was still a good performing community, however some participants really struggled due to their old age and lack of previous smartphone usage.

Diare performed quite bad, due to the low attendance (best attendance was 14, but most of the time it was less). Another problem in Diare was the lack of male-female interaction. In Diare we did the training in a school building, where all the men were sitting in front, and the woman in the back. They also didn't ask a lot of questions and were less often at the training due to their cooking / cleaning duties. Most men that were consistently at the trainings in Diare performed quite well, showing the potential of this community.

Recommendations fieldwork preparation

In order to best prepare a similar project containing fieldwork in the coming years, we have created a list of encounters we would've liked to have solved or thought of beforehand. For a start, it became obvious that communication between the project leaders and our contact persons at UDS wasn't as spotless as we had hoped. Our supervisor of the project on the UDS side (Dr. Bizoola) was, though aware of our arrival, unaware of our plans with UDS and the farming communities. It was unclear that we would be revisiting the three old communities to organize a recap training and start a DROP-app training in the new communities. This also resulted in discussions surrounding the available budget from both WUR and UDS. It is customary in Ghana to not have to spend any of your own money on a project and have it reimbursed later. Moreover, as we were three students, funds were limited to suffice all advance payments. This time, we received advance payments from WUR halfway through the fieldwork, after personal money had already been spent. Though not an issue for us, it resulted in some conflict in the planning. This also resulted in an administration partly done by UDS and partly done by us when funds arrived. This caused frustration between us and UDS trying to align our administrations. Our recommendation is to make sure a budget for fieldwork expenses (i.e., car rental, driver, translator, fuel, motivational meals, etc) is communicated beforehand with UDS. Then it can be made sure that advance payments by Wageningen have succeeded before the start of the fieldwork.

In preparation for the fieldwork, it would be beneficial to apply translations to Dagbani of several questionnaires when a translator is no longer available. This will allow the literate participants to fill in questionnaires on their own and possibly collect data from those who are illiterate.

During the fieldwork, internet connection was limited in most communities, especially the smaller ones. The phones gifted to the communities were unable to receive data at all times and needed a hotspot of our own phones in order for the DROP app to work. For a future project, we would recommend a range extender that is able to pick up the signal and extend it to the project phones. These can be bought in Tamale for a reasonable price.
In case of further expansion towards new farming communities, we would suggest a selection of certain participants and their role/age/occupation in the community. We have experienced that the elders of the community are invited to participate in the training, however, their age and illiteracy are actively hindering them from understanding the purpose of the app and how to use it, as was seen in all communities at the end of the fieldwork. Moreover, people with status in the community are, naturally, invited to participate. Even though some of these usually own smartphones themselves and are literate, they are too busy to attend the training sessions. Additionally, if these participants are present, other farmers do not dare to speak up and discuss or ask questions. We suggest for further training, that younger farmers, who are all equal in role in the community be invited. Additionally, if the farmers invited have great knowledge of local forecasting, this would benefit the results of the project.

Recommendations for future fieldwork / DROP app

- Make the app compatible with older Android phones.

A lot of participants (especially in Nabogu), told us that they wanted to share the app with other farmers who had smartphones, but that the smartphones were often too old to support the app.

- Include indicators in DROP app.

The indicators in the KoboCollect did not work, because only about 25% of people in every group could read or write Dagbani. It is also much more work for them to have to go into a separate app, and people will forget it too.

- Add a time of expected rain.

People already like the app as it is, but in order to really be able to use it for everything, it would be useful if the app would be able to give an indication of the time of rain.

- Extra translator

If next year, people will be sent to Ghana again, it would help them a lot if there were 2 people that could do training in Dagbani. Because now, we were also just sitting around a lot while 1 person was helping Jamaldeen with the training. It would also allow you to be in 1 community for a lot longer, resulting in better training.

- Recap training before the next rainy season

Especially the new communities need to have a recap training before the next rainy season because they were not able to use the app a lot after the training had been completed. It will not even be necessary for someone from WUR to be there, Jamaldeen can do the training on his own if he is paid for it.

Limitations

Project limitations

A few limitations in the field made it more difficult for us to do our work. Firstly, the internet connection in Nabogu and Gushie was quite poor. Therefore, it was difficult to connect phones and tablets to the internet and use the DROP app. This delayed our training during each session, as phones would also disconnect during the training.
Furthermore, there was an obvious language barrier. Most farmers did not speak English, and we do not speak Dagbani. Therefore, we were dependent on our translator. However, we only had one translator, while we were with 3. If we would have had more translators, we perhaps could have done more work at the same time. To partially solve this issue, we asked one man from Nabogu, who was a teacher and spoke English, and the farmer leader of Gushie to help translate for us from time to time.

Another limitation was the literacy level of the farmers. Many farmers were illiterate. Therefore, it was difficult for them to understand the DROP App. It was even more difficult for them to understand the Kobo Collect, as this app is text-based and does not include icons to clarify. This made the collection of daily observations of indicators a challenge.
Lastly, we were in Ghana in September and October, at the end of the rainy season. For this reason, farmers could not use the app for many farming decisions, except harvesting. Furthermore, in the collection of daily observations of indicators, we miss indicators that might only be visible at the start of the rainy season.

Personal limitations

During our fieldwork, we had car troubles multiple times. This resulted in us arriving in the communities late or hampering us from leaving at all. Furthermore, we had to deal with being sick from malaria twice and we had to leave our accommodation in Nakpanzoo at one point due to an insect pest, which also delayed us.
Furthermore, we had to get used to and deal with the timeliness of the people in Ghana. Sometimes, we agreed to leave at 8 in the morning, but then the driver would not show up until 2 hours later. This was sometimes frustrating.

Appendix X – Documentation of Local Indicators

This appendix provides the results of the literature review on local rainfall and soil moisture indicators.

X.A - Documentation of Local Rainfall Indicators

X.A.1 – Animals

Amphibians

Table A.X - 1 Rainfall indicators based on amphibians.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Amphibians	-	Africa	Benin	Kandi, Glazoué & Zè commune	Behaviour of amphibians	-	Used in climate forecasting	Amegnaglo, Mensah-Bonsu & Anaman (2022)
Frog	-	Africa	Ghana	Northern region (Sandema community)	The croak of the ordinary frog	-	Signals time to sow	Ankrah, Kwapong & Boateng (2022)
Frog (Buntori)	-	Africa	Ghana	Northern region (Builsa South community)	The frog croaking throughout the night	-	Imminent rains	Ankrah, Kwapong & Boateng (2022)
Frog (khāifa)	-	Asia	India	Tangkhul Naga community (Northeast India)	Continuous croaking of frog	Summer	Sign of upcoming rainfall	Varah & Varah (2022)
Frog (pololi)	Xenopus laevis	Africa	Ghana	Kumbungu district (Northern Ghana)	High-pitched sound of frogs	Rainy season	Rain the next day	Nyadzi et al. (2021)

Frog (pololi)	Xenopus laevis	Africa	Ghana	Kumbungu district (Northern Ghana)	High-pitched frog sounds	Dry season	Indicates onset of rains up to a week. The intensity of this sound (the louder it gets) indicates a good season with normal or wetter season	Nyadzi et al. (2021)
Frog (Sopena)	-	Africa	Ghana	Volta region (Ketu-North)	Frog croaking	-	Likelihood of rain. Whenever the frog croaks in the afternoon, it indicates the likelihood to rain in the evening	Ankrah, Kwapong & Boateng (2022)
Frogs	-	Africa	Nigeria	Delta state	Frogs croaking	-	Arrival of both early rain and rainy season	Ebhuoma (2020)
Frogs	-	Africa	Ghana	Wa West District	Frogs croaking	-	Indicates the start of the rainy season	Sullo et al. (2020)
Frogs	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Frogs croaking	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Frogs	-	Africa	Ghana	Western region (Sewfi	Frog croaking	-	Indicates the likelihood of rain.	Ankrah, Kwapong &

				Bosomoiso community)			Whenever the frog croaks in the evening, it indicates the likelihood of rain the next morning.	Boateng (2022)
Frogs	-	Africa	Ghana	Northern region (Yendi Municipality)	Frogs squeaking during the day	-	Rain will fall	Adanu, Abole & Gbedemah (2022)
Frogs/toads	-	Africa	Uganda	Rwenzori region	Start making noise	-	Indicator for the onset of rains (4.4%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Toad (Jamphatu)	Bufo bufo	South America	Bolivia	Ancoraimes municipality	-	September - March	Likelihood of rain and level of production (short-term forecast)	Gilles et al. (2022)
Toads (muuch (Maya), sapos (Spanish))	Bufonidae	North America	Mexico	Yucatán Peninsula	1. When toads croak during the night, 2. If the "*carillo múuch"* toad croaks during April nights	-	1. Rain will come within 3 days, 2. Hurricanes	Camacho-Villa et al. (2021)
White frog (Rwangach-ena)	Litoria caerulea	Africa	Zimbabwe	Bikita district	Sounding	-	Imminent rains, be prepared for cropping (-->	Mafongoya, Mafongoya & Mudhara (2021)

							get prepared for cropping)	

Birds

Table A.X - 2 Rainfall indicators based on birds.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Abdim's stork	Ciconia abdimii	Africa	Uganda	Rwenzori region	Appear in March and August; seen around November; fly in big numbers	-	Indicator for the onset of rains (0.4%), cessation of rains (1.0%), 5-day forecast (0.1%)	Nkuba et al. (2020)
Africa fish eagle	Haliaeetus vocifer	Africa	Uganda	Rwenzori region	Make noise	-	Indicator for cessation of rains (0.1%)	Nkuba et al. (2020)
African grey hornbill	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	African grey hornbill moving to the north (desert)	-	Rains are about to set in	Jabik (2022)
African grey hornbill	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	African grey hornbill returning to the south	-	Cessation of rainy season	Jabik (2022)
African weaver bird	-	Africa	Ghana	Upper East Region (Garu, Binduri,	Presence of groups of African	-	Onset of rainy season is close + good yields	Jabik (2022)

				Bawku West and Tempane districts)	weaver birds in the area		of the early millet	
African wood owl	Strix woodfordii	Africa	Uganda	Rwenzori region	Make noise	-	Indicator for onset of rains (0.8%)	Nkuba et al. (2020)
(Alikima)	-	Africa	Ethiopia	Gomole district	1. When the birds keep singing at midnight. 2. Birds are not singing	May	1. Imminent onset of good *ganna* rains, 2. Delay in rainy season or calamitous drought ahead	Dejene & Yetebarek (2022)
Amur falcons (lāngdik)	-	Asia	India	Tangkhul Naga community (Northeast India)	Migration of amur falcons at Shirui peak	Autumn	Good harvests	Varah & Varah (2022)
(Bararato)	-	Africa	Ethiopia	Gomole district	1. When the birds keep singing at midnight. 2. Birds are not singing	May	1. Imminent onset of good *ganna* rains, 2. Delay in rainy season or calamitous drought ahead	Dejene & Yetebarek (2022)
Bararaxxuu (*oola dhoottuu* = drought blinker)	-	Africa	Ethiopia	Burkitu watershed	The movement of the Bararaxxuu from east to west and back again, producing 'ba…ra…ra…ra'	-	Absence of rainfall	Guye, Legesse & Mohammed (2022)

Bird (Anomaa)	-	Africa	Ghana	Western region (Sewfi Wiaso community)	1. The sight of the bird in the community, 2. when the bird leaves the community	-	1. Time to cultivate yam, 2. Time for planting yam is over	Ankrah, Kwapong & Boateng (2022)
Birds	-	Africa	Nigeria	Delta state	Weaver birds	-	When nest is built very closely to the ground, it means that the floods on the low-lying farmlands for that season will be negligible. But when they build their nest at the middle or apex of a tree, it indicates heavy flooding for that season.	Ebhuoma (2020)
Birds	-	Africa	Ghana	Wa West District	Bird songs/nesting sites	-	Indicates the start of the rainy season	Sullo et al. (2020)
Birds	-	Africa	Uganda	Rwenzori region	Birds leaving Lake Albert to inland,	-	Indicator for onset of rains (0.1%),	Nkuba et al. (2020)

					following the wind direction		cessation of rains (0.1%)	
Birds	-	Africa	Ethiopia (eastern)	Somali community	When certain birds fly very high in the sky	-	Indicates drought	Mekonnen et al. (2021)
Birds	-	Africa	Ethiopia (eastern)	Somali community	When certain birds fly low	-	Indicates the coming of the rains	Mekonnen et al. (2021)
Birds	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Singing and chirping of birds	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Birds	-	Africa	Ghana	Northern region (Yendi Municipality)	Birds chirping	-	Rainfall will start	Adanu, Abole & Gbedemah (2022)
Birds	-	Africa	Benin	Kandi, Glazoué & Zè commune	Behaviour of birds is used in climate forecasting	-	-	Amegnaglo, Mensah-Bonsu & Anaman (2022)
Birds (alacheyu)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Birds building nests close to rivers or water bodies	-	Indicates below normal rainfall within the season	Nyadzi et al. (2021)
Birds (Bongobongo)	-	Africa	Ghana	Western region (Bonyere)	The sight of birds in a community	Around November	Onset of the dry season	Ankrah, Kwapong & Boateng (2022)
Birds' sound	-	Africa	Ethiopia	Burkitu watershed	Sounds of birds like Urdudde, Sololiya,	-	-	Guye, Legesse & Mohammed (2022)

					Laakkama, Gaarrisa and Qottoo are transliterated			
Black-and-white-casqued hornbill	Bycanistes subcylindricus	Africa	Uganda	Rwenzori region	Feed on fruits and berries	-	Indicator for onset of rains (0.2%)	Nkuba et al. (2020)
Black bird (Humoya)	-	Africa	Ethiopia (eastern)	Somali community	When Humoya sings between midnight and dawn	-	Sign of good rain season	Mekonnen et al. (2021)
Blue-headed coucal	Centropus monachus	Africa	Uganda	Rwenzori region	Fly in big numbers	-	Indicator for the onset of rains (0.9%), 5-day forecasts (0.2%)	Nkuba et al. (2020)
Cattle egret	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Appearance of the cattle egret	-	Rainy season is near	Baffour-Ata et al. (2021)
Cattle Egret (bird)	-	Africa	Ghana	Wa West District	Cattle Egret bird following sheep or cattle	-	Indicates the start of the rainy season	Sullo et al. (2020)
(Ch'ijta)	Phrygilus plebejus	South America	Bolivia	Umala municipality	-	August - October	Whether year will be wet or dry (seasonal forecast)	Gilles et al. (2022)

Chachalaca (Baach (Maya))	Ortalis vetula	North America	Mexico	Yucatán Peninsula	Chachalaca song is used to predict imminent rain or drought. 1. If the bird sings during the afternoon, 2. If the bird sings in the morning	-	1. It will take time to rain, 2. There will be rains in the next 2-3 days	Camacho-Villa et al. (2021)
Common myna	Acridotheres tristis	Asia	Nepal	Kirtipur	Timing of feathers of the common myna falling	-	If the feathers fall early, the rainy season will end early. If the feathers fall late, the rainy season will not stop soon.	Poudel et al. (2022)
Coucal bird (alacheyu)	Centropus sinensis	Africa	Ghana	Kumbungu district (Northern Ghana)	Loud singing of coucal bird	-	Rains in the next few days	Nyadzi et al. (2021)
Crested crane	Balearica regulorum	Africa	Uganda	Rwenzori region	Seed eaters make noise; move toward river Semiliki	-	Indicator for the onset of rains (1.4%), cessation of rains (0.1%)	Nkuba et al. (2020)
Crow	-	Asia	Nepal	Kirtipur	When a crow makes its nest, and it 1. picks the stick up	-	1. Rain will come in early Asar (Asar = mid-June to	Poudel et al. (2022)

					from its right side, 2. directly in front, 3. from its left side		mid-July), 2. Summer rain is to ben in the mid-Asar, 3. Rains will fall at the end of the month or in the next month only	
Crow (Gunguwo)	Genus corvus	Africa	Zimbabwe	Bikita district	Flying in skies	-	Indicates dry spells	Mafongoya, Mafongoya & Mudhara (2021)
Crow and other black birds	-	Africa	Ghana	Northern region (Yendi Municipality)	Crow and other black birds circling in groups high up in the sky	-	Good weather for rain to fall	Adanu, Abole & Gbedemah (2022)
Crows (alacheyu)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Crows flying in groups	-	Indicates a normal season	Nyadzi et al. (2021)
Cuckoo (Koktui)	-	Asia	India	Tangkhul Naga community (Northeast India)	Appearance and singing of the cuckoo	March (Mayo season)	Time to sow seeds	Varah & Varah (2022)
Cuckoo (kowhera)	Cuckoo cuculiformes	Africa	Zimbabwe	Bikita district	Sounding	-	Imminent rains (--> get prepared for cropping)	Mafongoya, Mafongoya & Mudhara (2021)
Cuckoo birds	-	Africa	Ghana	Upper East Region (Garu, Binduri,	Cuckoo birds make sounds	-	Rains is about to set in	Jabik (2022)

				Bawku West and Tempane districts)				
Doves: tambourine dove, blue-spotted wood dove, lemon dove, red-eyed dove	Turtur tympanistria, Turtur afer, Aplopelia larvata, Streptopelia semitorquata	Africa	Uganda	Rwenzori region	Make noise	-	Indicator for the onset of rains (1.0%), cessation of rains (0.1%), 5-day forecast (0.1%)	Nkuba et al. (2020)
Duck (gbinyafu)	Anas Platyrhynchos	Africa	Ghana	Kumbungu district (Northern Ghana)	Ducks rapidly flapping and stretching their wings while playing in the soil	-	Onset of rains	Nyadzi et al. (2021)
Ducks	-	Africa	Nigeria	Delta state	Ducks flapping their wings	-	Onset of the rainy season	Ebhuoma (2020)
Ducks and ducklings	-	Africa	Ghana	Northern region (Yendi Municipality)	Ducks and ducklings seen running, flapping their wings and bathing in the sand	-	Impending rainfall	Adanu, Abole & Gbedemah (2022)
Eagles: brown snake eagle, western banded snake eagle, Congo serpent eagle, Verreaux's eagle, long-	Circaetus cinereus, Circaetus cinerascens, Dryotriorchis spectabilis, Aquila verreauxi,	Africa	Uganda	Rwenzori region	Fly in big numbers; appear in season and then disappear	-	Indicator for the onset of rains (5.0%), cessation of rains (0.4%), 5-day forecast (0.6%)	Nkuba et al. (2020)

crested eagle, crowned eagle, martial eagle	Aquila wahlbergi, Lophaetus occipitalis, Steph-anoaetus coronatus, Polemaetus bellicosus							
Egrets: cattle egret and little egret	Bubulus ibis; egreeta garzetta	Africa	Uganda	Rwenzori region	Move with cattle, as cattle graze; move toward River Semiliki	-	Indicator for the onset of rains (4.2%), cessation of rains (1.8%), 5-day forecast (0.8%), seasonal forecast (0.6%)	Nkuba et al. (2020)
Egyptian plover	-	Africa	Ghana	Northern region (Yendi Municipality)	Egyptian plover flying high in the sky	-	Good weather for rain to fall	Adanu, Abole & Gbedemah (2022)
Esankuye bird	-	Africa	Ethiopia (eastern)	Somali community	Esankuye bird produces sharp sounds during the night	-	Sign of good rain season	Mekonnen et al. (2021)
Goose (Wallata)	Chlophaga melanoptera	South America	Bolivia	Ancoraimes municipality	-	September - December	Level of production and rain likelihood (seasonal forecast)	Gilles et al. (2022)

Gray parrot	Psitacus eithacus	Africa	Uganda	Rwenzori region	Make noise	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)
Gurgudde	-	Africa	Ethiopia	Gomole district	1. When the bird sings for a long time at midnight and makes two types of sounds, 2. When the bird sings for a short time (two or three times)	-	1. Imminent rainfall onset and good season, 2. Imminent drought incidences (scanty rains)	Dejene & Yetebarek (2022)
Hadada ibis	Bostrychia hagedash	Africa	Uganda	Rwenzori region	Feed on worms and insects; wetland bird; make noise in the afternoon	-	Indicator for the onset of rains (0.1%), cessation of rains (0.6%), seasonal forecast (0.1%)	Nkuba et al. (2020)
Hawks	-	Africa	Ghana	Northern region (Yendi Municipality)	Hawks flying high in the sky	-	Good weather for rain to fall	Adanu, Abole & Gbedemah (2022)
Hlahlame-dupe bird	-	Africa	Zimbabwe	Limpopo Province	Singing of the Hlahlamedupe bird	October/November	Below average rainfall coming rainy season	Andersson et al. (2020)
Hornbill (hangkhok khalāng)	-	Asia	India	Tangkhul Naga community (Northeast India)	Flock of hornbills passing through the	April	Indicates abundant rains	Varah & Varah (2022)

					Tangkhul region very low, with its music or tunes more audible			
Hornbill (hangkhok khalāng)	-	Asia	India	Tangkhul Naga community (Northeast India)	Flock of hornbills passing through the Tangkhul region high, and their sound is muffled	April	Indicates and impending monsoon	Varah & Varah (2022)
Hornbill (hangkhok khalāng)	-	Asia	India	Tangkhul Naga community (Northeast India)	Appearance of hornbill	Autumn	Indicates that there will be plenty of rain in the coming season	Varah & Varah (2022)
Hornbills (alacheyu)	Bucerotdae	Africa	Ghana	Kumbungu district (Northern Ghana)	The movement of a large numbers of Hornbills with loud singing	-	Indication of a good rainy season	Nyadzi et al. (2021)
Lake ducks: yellow-billed duck, African black duck	Anas undulata, Anas sparsa	Africa	Uganda	Rwenzori region	Leave water and move to dry land	-	Indicator for the onset of rains (1.4%), cessation of rains (0.3%), 5-day forecast (0.2%)	Nkuba et al. (2020)

Laughing falcon (Koos (Maya), guaco (Spanish))	Herpetotheres cachinnans	North America	Mexico	Yucatán Peninsula	The time of laughing falcon song. 1. If it sings during the morning, standing on a green branch, 2. If it sings in the afternoon on a dry branch	-	1. It will rain, 2. There will be drought or very few or delayed rains (seasonal prediction)	Camacho-Villa et al. (2021)
Lesser flamingo	Phoeniconaias minor	Africa	Uganda	Rwenzori region	Appear in March and August; move toward River Semiliki	-	Indicator for the onset of rains (0.3%), cessation of rains (0.1%), 5-day forecast (0.2%)	Nkuba et al. (2020)
Liki liki (Bird)	Vanellus resplendens	South America	Bolivia	Umala municipality	-	October - December	Whether the year will be wet or dry, type of year, hail and lightning (seasonal forecast)	Gilles et al. (2022)
Liki liki (Bird)	Vanellus resplendens	South America	Bolivia	Ancoraimes municipality	-	September - November	Likelihood of rain, hail and lightning and level of production	Gilles et al. (2022)

							(seasonal production)	
Loons	-	North America	Canada	Pond Inlet, Nunavut	When they hear loons make a certain type of call (ka-ka-ka)	-	Rain is on its way	Simonee et al. (2021)
Marabou stork	Leptoptilos crumeniferus	Africa	Uganda	Rwenzori region	Move from Lake Albert to inland	-	Indicator for the onset of rains (0.8%), cessation of rains (2.0%), 5-day forecast (0.1%), seasonal forecast (0.1%)	Nkuba et al. (2020)
Migratory bird named Kharamva	-	Asia	India	Tangkhul Naga community (Northeast India)	Kharamva visits in and around the fields of the region from lands beyond the Himalayas	May	Indicates rain	Varah & Varah (2022)
Moorhen	-	Africa	Nigeria	Delta state	Moorhen, commonly known as swamp chicken, makes strange sounds.	-	Onset of the rainy season	Ebhuoma (2020)
Ngozha quelea birds	Quelea quelea	Africa	Zimbabwe	Bikita district	Visiting the area before	-	Be prepared for a bumper	Mafongoya, Mafongoya &

					and during farming season		harvest and also intensive growing of small grain crops such as millet, rapoko, and sorghum	Mudhara (2021)
Nightingale (Sampheirok)	-	Asia	India	Tangkhul Naga community (Northeast India)	Appearance and singing of the nightingale	March (Mayo season)	Time to sow seeds	Varah & Varah (2022)
Nightjars: montane nightjar, Ruwenzori nightjar, pennant-winged nightjar	Caprimulgus piliophalus, Caprimulgus ruwenzori, Macrodipteryx vexillarius	Africa	Uganda	Rwenzori region	Appear in March and August, fly in big numbers	-	Indicator for the onset of rains (0.7%), cessation of rains (0.1%), 5-day forecast (0.1%)	Nkuba et al. (2020)
Northern gray-headed sparrow	Passer griseus	Africa	Uganda	Rwenzori region	Make noise	-	Indicator for 5-day forecasts (0.2%)	Nkuba et al. (2020)
Orange Oriole (Yuya (Maya), calandria (Spanish))	Icterus auratus	North America	Mexico	Yucatán Peninsula	The size and characteristics of Orange Oriole nests. 1. Long nests with green leaves, 2. Long nests with dry leaves	April - May	1. Long drought as chicks will have more air, 2. Rainfall will arrive soon, and planting can be prepared in April	Camacho-Villa et al. (2021)

Owl (alacheyu)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Owl hooting in the evening	-	Onset of rain	Nyadzi et al. (2021)
Palawan hornbill	-	Asia	Philippines	Samar province, municipality of Basey	When the bird suddenly stops chirping during the day	-	A typhoon or heavy rainfall is about to come	Cuaton & Su (2020)
Pangolin (sāham)	-	Asia	India	Tangkhul Naga community (Northeast India)	Appearance of pangolin	Autumn	Indicates that there will be plenty of rain in the coming season	Varah & Varah (2022)
Pied crow	Corvus albus	Africa	Uganda	Rwenzori region	Move near homes; come to feed on insects	-	Indicator for the onset of rains (2.5%), cessation of rains (0.6%), 5-day forecast (0.2%)	Nkuba et al. (2020)
Pied kingfisher	Ceryle rudis	Africa	Uganda	Rwenzori region	Make noise	-	Indicator for the onset of rains (0.2%), cessation of rains (0.2%), 5-day forecast (0.1%)	Nkuba et al. (2020)
Robin-chats: Archer's robin-chat, blue-shouldered robin-chat,	Cossypha archeri, Cossypha cyano-campter,	Africa	Uganda	Rwenzori region	Come around November	November	Indicator for onset of rains (1.2%), 5-day forecasts (0.4%)	Nkuba et al. (2020)

snowy-crowned robin-chat	Cossypha niveicapilla							
Ruddy ground (Chak mucuy (Maya), tortola (Spanish))	Columbina talpacoti	North America	Mexico	Yucatán Peninsula	1. If ruddy ground doves build their nests in the soil, 2. If they establish their nests in a tree	-	1. There will be droughts, 2. There will be rains (seasonal prediction)	Camacho-Villa et al. (2021)
Rufous hornbill	-	Asia	Philippines	Samar province, municipality of Basey	When the bird suddenly stops chirping during the day	-	A typhoon or heavy rainfall is about to come	Cuaton & Su (2020)
Southern ground hornbill (Dendera)	Bucorvis leadbeateri	Africa	Zimbabwe	Bikita district	Sounding	-	Imminent rains (--> get prepared for cropping)	Mafongoya, Mafongoya & Mudhara (2021)
Sparrow hawk (i'koos (Maya), gavilán (Spanish))	-	North America	Mexico	Yucatán Peninsula	The height at which the sparrow hawk sings. 1. Near the soil, 2. High in the sky	-	1. Rain, 2. Prolonged drought (seasonal forecast)	Camacho-Villa et al. (2021)
Sparrows (Mherepere)	Passerdae	Africa	Zimbabwe	Bikita district	Flying over skies	-	Usually means a good season	Mafongoya, Mafongoya & Mudhara (2021)
Speckled mousebird	Colius striatus	Africa	Uganda	Rwenzori region	Fruit and nectar eater	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)

Sun bird (Chivangazuva)	-	Africa	Zimbabwe	Bikita district	Sounding	-	Means coming of dry spell or rains are still away	Mafongoya, Mafongoya & Mudhara (2021)
Swallow ("Nzun-gululu")	-	Africa	Kenya	Kitui Central	Flying groups towards one direction	-	Rains expected in the next 1 or 2 days	Mugi-Ngenga et al. (2021)
Swallows: Birds (alacheyu)	Hirundinidae	Africa	Ghana	Kumbungu district (Northern Ghana)	Large flocks of swallow birds migrating with loud sound	-	Rain onset in few days up to about a week	Nyadzi et al. (2021)
Swallows: Mosque swallow, lesser striped swallow, red-romped swallow	Hirundo senegalensis, Hirundo abyssinica, Hirundo daurica	Africa	Uganda	Rwenzori region	African and European migrants feed on insects; appear in season and disappear; fly in big numbers and play in the dust	-	Indicator for the onset of rains (4.6%), cessation of rains (0.7%), 5-day forecast (0.7%), seasonal forecast (0.1%)	Nkuba et al. (2020)
Tiki tiki o Phiskillo (Bird)	-	South America	Bolivia	Umala municipality	-	October - December	Whether the year will be wet or dry, type of year, probability of hail (seasonal forecast)	Gilles et al. (2022)
Tiki tiki o Phiskillo (Bird)	-	South America	Bolivia	Ancoraimes municipality	-	August - November	Likelihood of rain next cropping year, production	Gilles et al. (2022)

							level and likelihood of frost (seasonal forecast)	
Tuju (Bird)	Ctenomys opimus	South America	Bolivia	Umala municipality	-	August - September	Whether the year will be wet or dry (seasonal forecast)	Gilles et al. (2022)
Turacos: black-billed turaco, Rwenzori turaco, Ross's turaco, great blue turaco	Turaco schuetti, Ruwenzoromis johnstoni, Musophaga rossae, Corythaeola Cristata	Africa	Uganda	Rwenzori region	Makes noise; appear in March and August; play in the dust	-	Indicator for the onset of rains (5.5%), cessation of rains (5.0%), 5-day forecast (1.4%), seasonal forecast (0.8%)	Nkuba et al. (2020)
Urduddee	-	Africa	Ethiopia	Burkitu watershed	When Urduddee chants in mass and repeatedly makes the sound 'bekke..kko…bekke…kko'	-	Rain is approaching and the season is favourable for people and livestock	Guye, Legesse & Mohammed (2022)
Wagtails: Gray wagtail, mountain wagtail	Motacilla cinerea, Motacilla clara	Africa	Uganda	Rwenzori region	Make noise	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)

Weaver birds: Baglafecht weaver, black-necked weaver, spectacled weaver, strange weaver, village weaver, brown-capped weaver	Ploceus baglafecht, Ploceus nigricollis, Ploceus ocularis, Ploceus alienus, Ploceus cucullatus, Ploceus insignis	Africa	Uganda	Rwenzori region	Make noise	-	Indicator for onset of rains (0.2%)	Nkuba et al. (2020)
White browed coucal	Centropus uperciliosus	Africa	Uganda	Rwenzori region	Male makes call; moves in evening 16.00 - 17.00 local time	-	Indicator for the onset of rains (35.7%), cessation of rains (0.9%, 5-day forecast (9.8%), seasonal forecast (2.6%)	Nkuba et al. (2020)
White cattle egret	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	When groups of the white cattle egrets are observed to be migrating from the east to the west	-	Rains are about to cease	Jabik (2022)
White stock bird (Usvore)	Ciconia ciconia	Africa	Zimbabwe	Bikita district	Visits by these migrant birds	-	Good season (since the	Mafongoya, Mafongoya &

							birds stay in wet and humid places) (--> be prepared for a bumper harvest and also intensive growing of small grain crops such as millet, rapoko, and sorghum)	Mudhara (2021)
White wagtail (Pāizteo)	-	Asia	India	Tangkhul Naga community (Northeast India)	1. White wagtail builds its nest lower above the river water level, 2. White wagtail builds its nest high above the river water level	Summer	1. Untimely arrival of the monsoon and scanty rain that year, 2. Timely arrival and bountiful rain	Varah & Varah (2022)
White-eared brown dove	-	Asia	Philippines	Samar province, municipality of Basey	When the bird suddenly stops chirping during the day	-	A typhoon or heavy rainfall is about to come	Cuaton & Su (2020)
Duck (gbinyafu)	Anas Platyrhynchos	Africa	Ghana	Kumbungu district (Northern Ghana)	Ducks rapidly flapping, stretching their wings	-	Rains in few hours and up to the next day	Nyadzi et al. (2021)

					with loud quack sound			

Centipedes

Table A.X - 3 Rainfall indicators based on centipedes.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Millipedes	-	Africa	Nigeria	Delta state	Appearance of tiny red-like millipedes in groups	-	Onset of the rainy season	Ebhuoma (2020)
Millipedes	-	Africa	Ghana	Wa West District	Movement of millipedes	-	Indicates the start of the rainy season	Sullo et al. (2020)
Millipedes	-	Africa	Uganda	Rwenzori region	Seen around homes; move to the forest	-	Indicator for the onset of rains (1.5%), cessation of rains (0.4%)	Nkuba et al. (2020)
Millipedes (Mazon-gororo)	Diplopoda	Africa	Zimbabwe	Bikita district	When seen moving around	-	Imminent rains (--> be prepared for cropping)	Mafongoya, Mafongoya & Mudhara (2021)
Millipedes (Mazon-gororo)	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Movement of millipedes	-	Used to predict rainfall	Baffour-Ata et al. (2021)

Fish

Table A.X - 4 Rainfall indicators based on fish.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Fish	-	Africa	Uganda	Rwenzori region	Go to deep waters and do not lay eggs	-	Indicator for onset of rains (0.2%), cessation of rains (0.2%)	Nkuba et al. (2020)
Fish	Bagrus docmak, Clarias gariepinus	Africa	Uganda	Rwenzori region	Catfish locally called semutundu; mudfish; catfish locally called Male are available in the lake	-	Indicator for onset of rains (0.3%)	Nkuba et al. (2020)
Fish	-	Africa	Uganda	Rwenzori region	Fish reduce in numbers in the lake; Lungfish (Protopterus aethiocipus) more available	-	Indicator for cessation of rains (0.1%)	Nkuba et al. (2020)
Fish	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	Plenty of fish at the edges of lake, river, or sea	-	There are going to be heavy rains and floods causing abundance; thus, rice is	Limpo et al. (2022)

							suitable for planting	

Insects

Table A.X - 5 Rainfall indicators based on insects.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Ants	-	Asia	Vietnam	Quang Nam province	The movement patterns of ants: i.e. - ascending or descending surfaces, - seeking shelter within structures	-	Heavy rain occurs within 2 - 3 days	Van Huynh et al. (2020)
Ants	-	Africa	Ethiopia (eastern)	Somali community	When black ants move forth and back forming one route from their hole	-	Bad season to come	Mekonnen et al. (2021)
Ants	-	Africa	Ethiopia (eastern)	Somali community	When black ants move forth and back forming more than four routes from their holes	-	Good season to come	Mekonnen et al. (2021)

Ants	-	Africa	Ethiopia (central)	Oromo community	Roaming of red ants around home	-	-	Mekonnen et al. (2021)
Ants (Kisimira)	-	South America	Bolivia	Ancoraimes municipality	-	December - April	Likelihood of rain next cropping year, production level and likelihood of frost (seasonal forecast)	Gilles et al. (2022)
Ants (salinsahi)	Lepisiota capensis	Africa	Ghana	Kumbungu district (Northern Ghana)	A lepisiota ant carrying its eggs uphill	Rainy season	Rain the next day or in few hours	Nyadzi et al. (2021)
Ants (salinsahi)	Lepisiota capensis	Africa	Ghana	Kumbungu district (Northern Ghana)	A rapid increase in anthills in the surroundings	Rainy season	Rains the next day or up to 3 days	Nyadzi et al. (2021)
Ants (salinsahi)	Lepisiota capensis	Africa	Ghana	Kumbungu district (Northern Ghana)	Lepisiota ant carrying its eggs uphill	Dry season	Rainfall onset approaching in up to a week time	Nyadzi et al. (2021)
Ants (salinsahi)	Lepisiota capensis	Africa	Ghana	Kumbungu district (Northern Ghana)	Lepisiota ant carrying its eggs from uphill to downhill	Rainy season	Rain cessation in few days up to a week	Nyadzi et al. (2021)
Ants (salinsahi)	Eciton burchellii	Africa	Ghana	Kumbungu district (Northern Ghana)	Large army ants in and around house	-	Indicate start of the rainfall onset, and as such a wetter	Nyadzi et al. (2021)

							normal in the rainy season	
Ants (salinsahi)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Rapid increase in anthills on farm ways	-	Onset of rains in few days for up to 1 or 2 weeks	Nyadzi et al. (2021)
Ants (síinik (Maya), hormigas (Spanish))	Formicidae	North America	Mexico	Yucatán Peninsula	1. Ants leave the anthill and take their eggs to a more secure place, 2. Ants protect their anthill digging around and putting soil in the entrance for avoiding floods, 3. Various species start flying	-	Both 1, 2 and 3 predict rain (short-term forecast)	Camacho-Villa et al. (2021)
Ants (síinik (Maya), hormigas (Spanish))	Formicidae	North America	Mexico	Yucatán Peninsula	When army ants collect and store food	-	Drought	Camacho-Villa et al. (2021)
Ants (zāling)	-	Asia	India	Tangkhul Naga community (Northeast India)	Ant habitat shifting with all their young larvae	Summer	Indicates heavy rains	Varah & Varah (2022)
Appearance of red ants	-	Africa	South Africa	Limpopo Province	-	-	-	Kom et al. (2022)

				(Vhembe District)				
Beehives	-	Asia	Vietnam	Quang Nam province	When beehives are situated in a low position	-	Indicates heavy rains or flooding	Van Huynh et al. (2020)
Bees	-	Africa	Uganda	Rwenzori region	Become inactive	-	Indicator for cessation of rains (0.2%)	Nkuba et al. (2020)
Bees	-	Africa	Ethiopia (central)	Oromo community	Bee migration to lowland	-	Better rainfall at lowland	Mekonnen et al. (2021)
Bees	-	Africa	Kenya	Tharaka South	Change in their behaviour and moving in colonies towards Mt. Kenya	-	Inadequate rains	Mugi-Ngenga et al. (2021)
Beetles (K'an ixím (Maya), escarabajo (Spanish))	Coleoptera	North America	Mexico	Yucatán Peninsula	If during the nights of May there are too many beetles on the floor or flying around the lights	May	Sign of good harvest	Camacho-Villa et al. (2021)
Black ants	-	Africa	South Africa	Limpopo Province (Vhembe District)	-	-	-	Kom et al. (2022)
Black ants	-	Africa	Ethiopia	Burkitu watershed	When a shoal of black ants moves in a scattered	-	Long dry season or drought is predicted	Guye, Legesse & Mohammed (2022)

					mood carrying a piece of chopped leaf			
Black ants	-	Africa	Ethiopia	Burkitu watershed	When black ants move densely in a straight line by sticking together	-	Good chance of rain	Guye, Legesse & Mohammed (2022)
Black ants	Lasius niger	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	When many black ants are observed	Onset of rainy season	Many rains in that year	Jabik (2022)
Black ants	Lasius niger	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	When the ants are observed carrying their larvae from lower land to higher grounds (mostly by the river side)	-	Likelihood of flooding in the next few days	Jabik (2022)
Black witch butterflies (x'mahaná (Maya), mariposa nocturna (Spanish))	Ascalapha odorata	North America	Mexico	Yucatán Peninsula	When black with butterflies enter the house during the day	-	It will rain within 3 days (people think that it is asking permission to stay safe at home and	Camacho-Villa et al. (2021)

							escape from rain)	
Butterflies	Lepidoptera (order)	Africa	Uganda	Rwenzori region	Fly toward Lake Albert	-	Indicator for onset of rains (0.8%), cessation of rains (10.3%), 5-day forecasts (0.4%)	Nkuba et al. (2020)
Butterflies	-	Africa	Uganda	Rwenzori region	Many butterflies	-	Drought, seasonal forecast (0.1%)	Nkuba et al. (2020)
Butterflies	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Appearance of butterflies	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Butterflies	-	Africa	Ethiopia	Burkitu watershed	Sudden invasion of a swarm of butterflies	-	Arrival of rain	Guye, Legesse & Mohammed (2022)
Butterflies (kahinpie)	Amblyscirtes	Africa	Ghana	Kumbungu district (Northern Ghana)	A large number of butterflies continuously flapping their wings in the skies without taking shelter on leaves	-	Rain in few hours to the next day	Nyadzi et al. (2021)

Butterflies (kahinpie)	Amblyscirtes	Africa	Ghana	Kumbungu district (Northern Ghana)	A large number of migrating butterflies	-	Indicates onset and a season with good rains	Nyadzi et al. (2021)
Butterflies (konghār)	-	Asia	India	Tangkhul Naga community (Northeast India)	Migration of butterflies	Autumn	Onset of rain	Varah & Varah (2022)
Caterpillars	-	Africa	Uganda	Rwenzori region	Feed on crops	-	Indicator for cessation of rains (1.4%)	Nkuba et al. (2020)
Caterpillars (madora)	Lepidopteran	Africa	Zimbabwe	Bikita district	Moving around in abundance	-	Good season (--> be prepared for bumper harvest)	Mafongoya, Mafongoya & Mudhara (2021)
Caterpillars (thingkalom)	-	Asia	India	Tangkhul Naga community (Northeast India)	Disappearance of caterpillars	Autumn	Indicates less or no rainfall in the coming winter	Varah & Varah (2022)
Caterpillars (zunzuya)	Larva	Africa	Ghana	Kumbungu district (Northern Ghana)	Woolly bear caterpillars scurrying and burrowing into the soil	-	Rainfall the next day or up to few days	Nyadzi et al. (2021)
Christmas beetle (nyezhe/nyenze)	-	Africa	Zimbabwe	Bikita district	Heavy sounding	-	Imminent rains (--> be prepared for cropping)	Mafongoya, Mafongoya & Mudhara (2021)
Cicada (rereva)	-	Asia	India	Tangkhul Naga community (Northeast India)	The song of the cicada	Summer	Indicates rainfall. The louder, the	Varah & Varah (2022)

							more rainfall is expected	
Cicadidae	Cicadidae	Asia	Indonesia	Jawa	Species of Cicadidae making an appealing sound	-	Beginning of the rainy season	Zaki et al. (2020)
Cockroaches (k'uuruch (Maya), cucarachas (Spanish))	Blattodea	North America	Mexico	Yucatán Peninsula	When cockroaches flutter around the houses	-	It will rain within 3 days (it is assumed that these insects feel the heat and humidity)	Camacho-Villa et al. (2021)
Crickets	-	Africa	Ghana	Wa West District	Chirping of crickets	-	Indicates the start of the rainy season	Sullo et al. (2020)
Crickets	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Chirping of crickets	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Dragonflies	Odonata (order)	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.2%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Dragonflies	Odonata (order)	Africa	Uganda	Rwenzori region	Decreases	-	Indicator for cessation of rains (0.1%)	Nkuba et al. (2020)
Dragonfly ("Ivandaa-thano")	-	Africa	Kenya	Kitui Central	Jumping up and down for a prolonged	-	Wet conditions approaching,	Mugi-Ngenga et al. (2021)

					period (a day or two)		meaning that land preparations should start	
Dragonfly ("Miunjuri")	-	Africa	Kenya	Tharaka South	Jumping up and down but very close to the ground for a prolonged period	-	Rains will begin, meaning that farmers should prepare accordingly and start planting	Mugi-Ngenga et al. (2021)
Dragonfly (Mukonikoni)	Anisoptera	Africa	Zimbabwe	Bikita district	When flying in numbers	-	Coming of rains (--> get prepared for cropping)	Mafongoya, Mafongoya & Mudhara (2021)
Flying termites (Mabhuru-rungwa)	Peticulitermes	Africa	Zimbabwe	Bikita district	When flying after rains	-	Coming of a dry spell (--> be prepared for the coming of the dry spell, and farmers need to intensify weeding)	Mafongoya, Mafongoya & Mudhara (2021)
Fruit flies (ātheihā-chāng)	-	Asia	India	Tangkhul Naga community (Northeast India)	When fruit flies are seen	Autumn	Time for harvest	Varah & Varah (2022)
Grasshoppers	Orthoptera (order),	Africa	Uganda	Rwenzori region	Move in big numbers	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)

	Acrididae (family)							
Grasshoppers	Orthoptera (order), Acrididae (family)	Africa	Uganda	Rwenzori region	Decreases	-	Indicator for cessation of rains (1.0%)	Nkuba et al. (2020)
Grasshoppers (khao)	-	Asia	India	Tangkhul Naga community (Northeast India)	Disappearance of grasshoppers	Autumn	Indicates less or no rainfall in the coming winter	Varah & Varah (2022)
Grasshoppers (mhashu/ma-gwatakwata/ madowindo)	Schtocerca americana	Africa	Zimbabwe	Bikita district	Appearing in large numbers or swarms	-	Means abundance of food (be ready for a fruitful season)	Mafongoya, Mafongoya & Mudhara (2021)
Honeybees (nyuchi)	Appis mellifera	Africa	Zimbabwe	Bikita district	When many and flying around	-	Abundant rains (since the bees depend on flowers) (--> be prepared for bumper harvest)	Mafongoya, Mafongoya & Mudhara (2021)
Hornets	-	Oceania	Fiji	Rakiraki, Gallau, Korotale & Wailevu	Hornets moving their hive to a lower level	-	Sign of upcoming cyclone	Nakamura & Kanemasu (2022)
House flies	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Presence of large numbers of house flies	Onset of rainy season	Favourable condition and the likelihood of a bumper harvest of	Jabik (2022)

							millet in that year	
Insect (Wuntenbaa)	-	Africa	Ghana	Northern region (Mogneigu community)	The sound of the insect	-	Imminent rains in 2 months	Ankrah, Kwapong & Boateng (2022)
Insect behaviours	-	Africa	Ethiopia	Burkitu watershed	Time and direction of the move of the swarms of insects are transliterated	-	-	Guye, Legesse & Mohammed (2022)
Insects	-	Africa	Benin	Kandi, Glazoué & Zè commune	Behaviour of insects is used in climate forecasting	-	-	Amegnaglo, Mensah-Bonsu & Anaman (2022)
Insects and butterflies	-	Africa	Ghana	Northern region (Yendi Municipality)	Appearance of certain insects and butterflies that get missing for the greater part of the dry season but suddenly appear. The butterflies are white and fly from north to south. When the butterflies return in a few days from the	Dry season	Rainy season is about to start	Adanu, Abole & Gbedemah (2022)

					south, they are multi-coloured.			
Insects, e.g., crickets	-	Asia	Philippines	Samar province, municipality of Basey	When insects like crickets intermittently stop making a sound for two-three minutes during the night	-	Earthquake is about to come	Cuaton & Su (2020)
Mosquitoes	Diptera (order), Culicidae (family)	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)
Mosquitoes (duunsi)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Frequent and painful bites of mosquitoes in the day	Rainy season	Rain the next day (latest up to 3 days)	Nyadzi et al. (2021)
Mosquitoes (duunsi)	Culicidae	Africa	Ghana	Kumbungu district (Northern Ghana)	Frequent and painful mosquito bites and high nuisance	Dry season	Rainfall onset in a few days up to a week	Nyadzi et al. (2021)
Moth	-	Asia	India	Tangkhul Naga community (Northeast India)	Appearance of a moth by dusk and night	May	Indicator of warm days	Varah & Varah (2022)
Moth (Afranfranto)	-	Africa	Ghana	Western region (Nyambekyere community)	The sight of the moth	-	Signifies the time to cultivate yam	Ankrah, Kwapong & Boateng (2022)

Moths	-	Africa	Uganda	Rwenzori region	Seen at night	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)
Red ants	Hymenoptera (order), Formicidae (family)	Africa	Uganda	Rwenzori region	Move in big numbers in a straight line	-	Indicator for onset of rains (4.6%), cessation of rains (0.3%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Red ants	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Appearance of red ants	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Red ants	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	Red ants are outside their nests and move to higher locations within the groups.	-	There are going to be heavy rains and floods causing abundance; thus, rice is suitable for planting	Limpo et al. (2022)
Safari ants	Hymenoptera (order), Formicidae (family)	Africa	Uganda	Rwenzori region	Feed on crops	-	Indicator for onset of rains (0.2%)	Nkuba et al. (2020)
Sand crickets (Makurwe)	Grylliade	Africa	Zimbabwe	Bikita district	Appearing in numbers	-	Be ready for a bumper harvest	Mafongoya, Mafongoya & Mudhara (2021)

Stomoxys	Diptera (order), Muscidae (family)	Africa	Uganda	Rwenzori region	Seen around homes; seen among cattle	-	Indicator for onset of rains (0.3%), cessation of rains (0.3%)	Nkuba et al. (2020)
Termites	Isoptera (order)	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)
Termites	-	Africa	Ethiopia (eastern)	Somali community	When termite problems (e.g., damage on crops) occur and their population increases	-	Bad season to come	Mekonnen et al. (2021)
Termites	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Appearance of termites	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Termites	-	Asia	Nepal	Kirtipur	A large number of flying termites on the ground	April	Rainfall is coming soon (--> sign to prepare the field for sowing maize)	Poudel et al. (2022)
Termites (majuru/ unheza)	Ancistroterme sp.	Africa	Zimbabwe	Bikita district	When seen collecting grass and stocking	-	Droughts	Mafongoya, Mafongoya & Mudhara (2021)
White ants	Isoptera (order)	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains	Nkuba et al. (2020)

							(0.3%), cessation of rains (0.1%)	

Mammals

Table A.X - 6 Rainfall indicators based on mammals.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Chimpanzees	-	Africa	Uganda	Rwenzori region	Come out of the forest; make noise	-	Indicator for onset of rains (0.1%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Chimpanzees	-	Africa	Uganda	Rwenzori region	Make noise	-	Indicator for cessation of rains (0.1%)	Nkuba et al. (2020)
Cow	-	Africa	Ghana	Northern region (Yendi Municipality)	Cows running very fast as if they are being chased, yet acting playfully and jumping around with their tails raised	-	Rain will fall in a few weeks	Adanu, Abole & Gbedemah (2022)
Cow (nafnya)	Bos Taurus	Africa	Ghana	Kumbungu district (Northern Ghana)	Cows repeatedly flapping their ears and tails	-	Rain the next day or up to 3 days	Nyadzi et al. (2021)
Cow (nafnya)	Bos Taurus	Africa	Ghana	Kumbungu district	Cows mostly standing and	-	Indicates the start of the	Nyadzi et al. (2021)

				(Northern Ghana)	looking restless		rainfall onset in a few days	
Cows and goats	-	Africa	Ethiopia	Burkitu watershed	Cows and goats expressing sexual urges and jump	-	Good chance of rain in the near future	Guye, Legesse & Mohammed (2022)
Cows dung	-	Africa	Ethiopia	Burkitu watershed	When cows drop dung while sleeping	-	Long dry season ahead	Guye, Legesse & Mohammed (2022)
Cows urinate	-	Africa	Ethiopia	Burkitu watershed	When a cow urinates while sleeping	-	Drought is about to happen	Guye, Legesse & Mohammed (2022)
Dogs	Canis lupus familiaris	Africa	Ghana	Kumbungu district (Northern Ghana)	When dogs loudly bark and run for cover in the day	-	Strong indication of rainfall onset in a few days. The louder the noise the dogs make the wetter the season is predicted to be.	Nyadzi et al. (2021)
Elephants	-	Africa	Uganda	Rwenzori region	Come out of the forest	-	Indicator for the onset of rains (0.1%), seasonal forecasts (0.1%)	Nkuba et al. (2020)
Elephants	-	Africa	Uganda	Rwenzori region	Stay in the forest	-	Indicator for the cessation of rains of the	Nkuba et al. (2020)

							rainy season (0.1%)	
Fox (Tiula)	Pseudalopex culpaeus	South America	Bolivia	Umala municipality	-	August - October	Planting time, where to plant and type of year (seasonal forecast)	Gilles et al. (2022)
Fox (Tiula)	Pseudalopex culpaeus	South America	Bolivia	Ancoraimes municipality	-	August - October	Planting time and place, production level (seasonal forecast)	Gilles et al. (2022)
Fox sound	-	Africa	Ethiopia	Burkitu watershed	Sound of foxes are transliterated	-	-	Guye, Legesse & Mohammed (2022)
Hippo-potamuses	-	Africa	Uganda	Rwenzori region	Start making noise	-	Indicator for the onset of rains (0.1%)	Nkuba et al. (2020)
Hyena (worabessa)	-	Africa	Ethiopia	Gomole district	When a hyena yawed early in the morning or late in the afternoon around 4 or 5 am and cannot eat when they find the remnants of dead animals	-	Rainfall onset is near	Dejene & Yetebarek (2022)
Hyenas	-	Africa	Ethiopia (central)	Oromo community	Hyenas screaming in a low tone	-	-	Mekonnen et al. (2021)

Livestock	-	Africa	Ethiopia (eastern)	Somali community	When livestock becomes skinny while good pasture, highly infested by pests (tick and lice) and disease outbreak	-	Indicator for upcoming drought	Mekonnen et al. (2021)
Livestock	-	Africa	Ethiopia	Burkitu watershed	When animals are startled and grow restless in their enclosures, or when bulls refuse to mate	-	Sign that the bad season is approaching	Guye, Legesse & Mohammed (2022)
Mammals	-	Africa	Benin	Kandi, Glazoué & Zè commune	Behaviour of mammals is used in climate forecasting	-	-	Amegnaglo, Mensah-Bonsu & Anaman (2022)
Moles (kafa) & voles (shiwoh)	-	Asia	India	Tangkhul Naga community (Northeast India)	Increased number of moles and voles	April	Indicates arrival of the warm season	Varah & Varah (2022)
Monkey (ma'ax (Maya), monos (Spanish))	Primates	North America	Mexico	Yucatán Peninsula	When monkeys howl during the night	-	It will rain soon	Camacho-Villa et al. (2021)

Rats	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	Rat holes are found in the middle to the top of the embankment	-	Heavy rains (floods) and plenty of rainy days	Limpo et al. (2022)
Rats	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	Rat holes are found in the middle of the rice field	-	A long dry season will take place	Limpo et al. (2022)
Rock rabbit (Mbira)	Ochotona collaris	Africa	Zimbabwe	Bikita district	Their squeaking	-	Indicates imminent rains or coming of *guti* (cloudy and humid conditions) (--> get prepared for cultivating crops)	Mafongoya, Mafongoya & Mudhara (2021)
Rodents	-	Asia	India	Tangkhul Naga community (Northeast India)	Rodents moving unusually and scurrying from their homes	Summer	Powerful earthquakes	Varah & Varah (2022)
Wild pigs	-	Asia	Philippines	Samar province, municipality of Basey	When wild pigs start collecting leaves and twigs to form or build a 'mini	-	A typhoon or heavy rainfall that might lead to flooding and landslide is	Cuaton & Su (2020)

					house' in a relatively flat and safe spot in the mountains		about to happen	

Multiple/other

Table A.X - 7 Rainfall indicators based on other animal categories or multiple animals.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Animal behaviour	-	North America	Canada	Pond Inlet, Nunavut	When rabbit, ptarmigan, and seals are not in their usual locations	-	Wind is on its way (animals sense the wind coming much sooner than humans)	Simonee et al. (2021)
Mashikikshira	-	Africa	Zimbabwe	Bikita district	When going into hiding in the ground	-	Imminent rains	Mafongoya, Mafongoya & Mudhara (2021)
Insect, bird and animal behaviour	-	Asia	Nepal	Thapuwa & Bikri (Gulariya municipality, Bardiya district)	Insect, bird and animal behaviours are considered biological indicators for flooding and droughts.	-	-	Chaudhary et al. (2021)

Reptiles

Table A.X - 8 Rainfall indicators based on reptiles.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Crocodiles	-	Africa	Uganda	Rwenzori region	Appear on riverbanks	-	Indicator for cessation of rains (0.2%)	Nkuba et al. (2020)
Iguana (huuh (Maya))	Iguana	North America	Mexico	Yucatán Peninsula	1. When iguanas make toad-like noises, 2. When iguanas lay eggs and bury them during May and June	-	1. Rains are coming, 2. Planting season (short- and medium-term forecast)	Camacho-Villa et al. (2021)
Monitor lizard (makwama)	Varanus griseus	Africa	Zimbabwe	Bikita district	When abundant in numbers	-	Good season	Mafongoya, Mafongoya & Mudhara (2021)
Reptiles (tiŋvura)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	The frequent appearance of reptiles such as snakes (family colubridae) wandering in the afternoon	-	Signals onset of rains in a week	Nyadzi et al. (2021)
Serpents (kan (Maya), serpiente (Spanish))	Serpentes	North America	Mexico	Yucatán Peninsula	When serpents climb trees	-	Rains (short-term forecast)	Camacho-Villa et al. (2021)

Snakes	-	Africa	Uganda	Rwenzori region	Snakes near homes	-	Indicator for onset of rains (0.2%), cessation of rains (0.1%)	Nkuba et al. (2020)
Snakes	-	Africa	Kenya	Kitui Central	Snakes invading their homesteads	-	Persistence of a dry spell	Mugi-Ngenga et al. (2021)
Snakes	-	Africa	Ethiopia (eastern)	Somali community	When snake population and biting increases	-	Coming season will be good and rainy	Mekonnen et al. (2021)
Snakes (phara)	-	Asia	India	Tangkhul Naga community (Northeast India)	Snakes moving unusually and scurrying from their homes	Summer	Powerful earthquakes	Varah & Varah (2022)
Tortoise	-	Africa	Ethiopia (eastern)	Somali community	When tortoise become more prevalent in the area	-	Coming season will be good and rainy	Mekonnen et al. (2021)

Spiders

Table A.X - 9 Rainfall indicators based on spiders.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Spider (Cusi Cusi)	Polybetes pythagoricus	South America	Bolivia	Ancoraimes municipality	-	May - July	Level of production (seasonal forecast)	Gilles et al. (2022)

Worms

Table A.X - 10 Rainfall indicators based on worms.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Earthworms	-	Africa	Uganda	Rwenzori region	Seen around homes	-	Indicator for onset of rains (0.2%)	Nkuba et al. (2020)
Earthworms (sambarigu)	Lumbricina	Africa	Ghana	Kumbungu district (Northern Ghana)	Appearance of a large number of earthworms on the day	-	Rains the next day or in a few hours	Nyadzi et al. (2021)
Sifenenefene worms	-	Africa	Zimbabwe	Limpopo Province	Large number of Sifenenefene worms	October	Above average rainfall coming rainy season	Andersson et al. (2020)

X.A.2 – Astronomy

Table A.X - 11 Rainfall indicators based on astronomy.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Full moon	-	Africa	Zambia	Sesheke district	Full moon	-	No rains are expected in the night and in the near term	Mushimbei & Libanda (2022)
Moon	-	Africa	Kenya	Tharaka South	When the moon is slightly tilted to the west, and the	September and October	Imminent rainfall	Mugi-Ngenga et al. (2021)

					crescent is facing down			
Moon	-	Africa	Ethiopia (eastern)	Somali community	The rise of new moon whereby its crescent is directed to the north (left)	-	Drought prevalence	Mekonnen et al. (2021)
Moon	-	Africa	Ethiopia (eastern)	Somali community	When crescent moon tilts to right	-	Coming season is hoped to bring good rains	Mekonnen et al. (2021)
Moon	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	-	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Moon	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	The crescent-shaped moon at the time of its appearance faces north and occurs the first night until the seventh night.	-	There will be a lot of wet days and heavy rainfall that year.	Limpo et al. (2022)
Moon	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	The sickle-shaped moon, concave to the south or north is used to predict drought or	-	-	Jabik (2022)

					floods, depending on the local name of the moon			
Moon (halo)	-	North America	Mexico	Yucatán Peninsula	When the moon appears with a halo or when it is in the last quarter	-	It is going to rain soon	Camacho-Villa et al. (2021)
Moon	-	Africa	Uganda	Rwenzori region	New moon is not clear/appears dark/reddish	-	Indicator for onset of rains (8.5%), cessation of rains (0.1%), 5-days forecasts (1.4%), seasonal forecasts (0.9%)	Nkuba et al. (2020)
Moon	-	Africa	Uganda	Rwenzori region	New moon is clear/bright	-	Indicator for cessation of rains (11.8%)	Nkuba et al. (2020)
Moon	-	Africa	Uganda	Rwenzori region	New moon is white	-	Indicator for onset of rains (0.3%)	Nkuba et al. (2020)
Moon (halo) (Goli)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	A yellow looking ring around the moon	-	Rains the next day or latest by 3 days	Nyadzi et al. (2021)

Moon (Goli)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	A downwards appearance of the moon crescent	-	Rains the next day or in a few hours	Nyadzi et al. (2021)
Moon (Goli)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Full moon covered by cloudlike appearance	-	Indicates a wetter than normal season	Nyadzi et al. (2021)
Moon (halo) (mwedzi)	-	Africa	Zimbabwe	Bikita district	Halo around moon	-	Indicates good season with normal or above-normal rains (--> get prepared for intensive farming)	Mafongoya, Mafongoya & Mudhara (2021)
Moon (ɔsramo)	-	Africa	Ghana	Western region (Bonyere)	When there is a full moon accompanied without rains	-	The next new moon signifies new rains to commence planting of crops	Ankrah, Kwapong & Boateng (2022)
Extra-terrestrial objects	-	Africa	Benin	Kandi, Glazoué & Zè commune	Behavior of extra-terrestrial objects (moon, sun & stars) is used in climate forecasting	-	-	Amegnaglo, Mensah-Bonsu & Anaman (2022)
Moon and stars	-	Africa	Ghana	Wa West District	Gathered moon and stars	-	Indicates change in season	Sullo et al. (2020)

Stars and moon	-	Africa	Ethiopia	Burkitu watershed	Position of the star and moon in the sky used as a reference to weather condition	-	-	Guye, Legesse & Mohammed (2022)
Bakalcha star	-	Africa	Ethiopia	Gomole district	1. When the bakalcha star slopes in the eastern horizon and resurfaces in the western horizon within seven days, 2. When bakalcha star slopes in the eastern horizon and resurfaces in the western horizon within 70 days	-	1. Imminent rainfall inception and a good rainfall season, 2. Slight rain	Dejene & Yetebarek (2022)
Binary stars (Lamii)	-	Africa	Ethiopia	Burkitu watershed	1. If Lamii (binary stars) is observed on the 15th night of September from 9 to 10 pm; 2. If Lami's alignment is	-	Indicates uncertainty of the upcoming short rainy season, 2. the next long dry season of the winter is normal, 3.	Guye, Legesse & Mohammed (2022)

					observed slightly above the moon in the north-east direction in mid-September at 9 pm; 3. If the constellations of the moon with Lamii are observed on the first day of the month of Bitdotteessa (April), at 9 pm, slightly below the moon in south-east direction		short dry season will last longer than expected	
Black stars	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)
Busana stars	-	Africa	Ethiopia	Gomole district	1. When busana (the group of 7 stars) appears in the eastern horizon and slope in the western horizon, 2.	-	1. Ganna rainy season will start approximately within a week, 2. Drought	Dejene & Yetebarek (2022)

					busana stars are not descended below the western horizon			
Orion's Belt (constellation)	-	South America	Bolivia	Umala municipality	-	August	Whether the year will be wet or dry (seasonal forecast)	Gilles et al. (2022)
Pleiades (Buusaa)	-	Africa	Ethiopia	Burkitu watershed	When Buusaa is seen (with vivid colour) in north-western direction and above the moon	December	Rainfall will be normal	Guye, Legesse & Mohammed (2022)
Pleiades (constellation)	-	South America	Bolivia	Ancoraimes municipality	-	June 24 - August	Quality of upcoming growing season	Gilles et al. (2022)
Sekgopetšana (a morning star/planet venus)	-	Africa	South Africa	Limpopo Province	Appearance of Sekgopetšana (a morning star/planet venus)	-	High probability of rainfall	Rankoana (2022)
Sirius (Basaa)	-	Africa	Ethiopia	Burkitu watershed	Observing Basaa in the south-west direction, slightly above the moon	August - October	Short fall of the rainy season by one or more months	Guye, Legesse & Mohammed (2022)

					between 7 and 9 pm			
Southern Cross (constellation)	-	South America	Bolivia	Umala municipality	-	May	Whether the year will be wet or dry (seasonal forecast)	Gilles et al. (2022)
Southern Cross (constellation)	-	South America	Bolivia	Ancoraimes municipality	-	May 3rd	Seasonal forecast	Gilles et al. (2022)
Star	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	A star shines brightly around 7.00 pm	-	Rainfall is abundant and the rainy days are lengthy	Limpo et al. (2022)
Star (Zikual, Zura)	-	Africa	Ethiopia (eastern)	Somali community	When the star locally called Zikual appears long in the sky for about 2 years; or locally named Zura star observed for more than two months in the sky and seen from east direction	-	The coming season will be bad, and drought will occur	Mekonnen et al. (2021)
Star (Zura, Duay)	-	Africa	Ethiopia (eastern)	Somali community	When Zura star is observed in	-	Coming of good season or rain	Mekonnen et al. (2021)

					the sky for long time, and it rotates from west direction; or locally named Duay star is observed in the sky in west direction			
Stars	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Stars moving from west to east	-	Rainfall onset in a few days	Nyadzi et al. (2021)
Stars	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Change in appearance (very bright) of the stars	-	Rainfall cessation in a week	Nyadzi et al. (2021)
Stars	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	-	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Stars	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	There are seven stars close to each other with bright lights that appear around 11.00 pm and set before dawn	-	The rains are abundant, and the number of wet days is long	Limpo et al. (2022)

Stars	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	Four stars appear in the west in the form of a parallelogram at approximately 7.00 pm	-	There will be plenty of rain. If the shape turns into a rectangle, it means the rain will stop.	Limpo et al. (2022)
Stars (unspecified)	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.1%), cessation of rains (2.9%), 5-day forecasts (0.7), seasonal forecasts (0.1%)	Nkuba et al. (2020)
Stars (unspecified)	-	Africa	Kenya	Kitui Central	3-5 stars seen appearing on the sky	-	More rains expected	Mugi-Ngenga et al. (2021)
Torban stars	-	Africa	Ethiopia	Gomole district	The *torban* stars are a group of seven stars situated in set of 3 and 4 respectively. 1. When the two stars among the seven of torban stars descend	-	*1. Ganna* rains will fall likely within the span of a week; 2. Shattering drought ahead	Dejene & Yetebarek (2022)

					below the western horizon late at night around 5 or 6 pm; 2. when the stars of torban appear in the western horizon and rains are not rained within the expected days			
Ursa major (constellation)	-	South America	Bolivia	Ancoraimes municipality	-	November	Level of production	Gilles et al. (2022)
Sun	-	Africa	Nigeria	Delta state	The sun becomes extremely scorching.	-	Arrival of the rainy season.	Ebhuoma (2020)
Sun	-	North America	Mexico	Yucatán Peninsula	1. When the sun has a crown of dominant blue colour, 2. When the sun has a crown and dominant red colour	-	1. It will rain soon, 2. There will be drought	Camacho-Villa et al. (2021)
Sun (wuntana)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	The appearance of a halo around the sun	Rainy season	Rain in the next day or few hours	Nyadzi et al. (2021)

Sun (wuntana)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	The appearance of shining spot around the sun	Dry season	Approaching good rainy season	Nyadzi et al. (2021)
Sun (zuva)	-	Africa	Zimbabwe	Bikita district	Halo around sun	-	Indicates good season with normal or above-normal rains (--> get prepared for intensive farming)	Mafongoya, Mafongoya & Mudhara (2021)

X.A.3 – Meteorology

Table A.X - 12 Rainfall indicators based on meteorology.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Cloud	-	Africa	Ghana	Northern region (Wenga community)	Cloud formation from the East towards the west	-	Likelihood to rain	Ankrah, Kwapong & Boateng (2022)
Cloud	-	Africa	Ghana	Northern region (Wenga community)	When the cloud formation starts from the east	-	Early rains	Ankrah, Kwapong & Boateng (2022)
Cloud	-	Africa	Ghana	Northern region (Wenga community)	When the clouds gather from the south	-	Indicates the middle of the season	Ankrah, Kwapong & Boateng (2022)

Cloud	-	Africa	Ghana	Northern region (Wenga community)	When the clouds gather in the west	-	Indicates late rains	Ankrah, Kwapong & Boateng (2022)
Cloud	-	Africa	Ghana	Northern region (Wenga community)	When the clouds gather from the north	-	Indicates close of the season	Ankrah, Kwapong & Boateng (2022)
Cloud	-	Africa	Ghana	Northern region (Mogneigu community)	A thick cloud in the eastern part	-	Rainfall	Ankrah, Kwapong & Boateng (2022)
Cloud	-	Africa	Ghana	Northern region (Mogneigu community)	Transformation of the east clouds turning red	-	Heavy rains	Ankrah, Kwapong & Boateng (2022)
Cloud (Alilikpo)	-	Africa	Ghana	Volta region (Zovie community)	Cloud formation in the eastern side	-	Onset of rains	Ankrah, Kwapong & Boateng (2022)
Cloud (Alilikpo)	-	Africa	Ghana	Volta region (Kave community)	Cloud formation in the south	-	Indicates a definite rain	Ankrah, Kwapong & Boateng (2022)
Cloud colour	-	Asia	Nepal	Kirtipur	1. White clouds, 2. Black or dark clouds, 3. Grey clouds	Monsoon (early June-September)	1. No rain, 2. Rain will come, 3. Strong winds	Poudel et al. (2022)
Clouds	-	Africa	Nigeria	Delta state	Cloud becomes dull.	-	Onset of both the early rains and the rainy seasons.	Ebhuoma (2020)

Clouds	-	Africa	Nigeria	Delta state	Elevated and thin clouds or low and thick clouds	December	Low amounts of early rains for the next planting season when the cloud is elevated and thin and vice versa.	Ebhuoma (2020)
Clouds	-	Africa	Ethiopia (central)	Oromo community	Change in the direction of cloud movements from normal	-	Expectation of the absence of rainfall (i.e., drought)	Mekonnen et al. (2021)
Clouds	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Cloud type and colour	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Clouds	-	Asia	Nepal	Kirtipur	The appearance of 'flaming' clouds on the horizon at daybreak	-	Onset of rain within a week	Poudel et al. (2022)
Clouds	-	Africa	Ghana	Northern region (Yendi Municipality)	Accumulated heavy dark to reddish coloured cloud rings that appear as solid rocks in the sky	-	Rain	Adanu, Abole & Gbedemah (2022)

Clouds	-	Africa	Ghana	Northern region (Yendi Municipality)	Dark grey clouds accompanied by strong winds that dislodge dry leaves on trees	-	Rain	Adanu, Abole & Gbedemah (2022)
Clouds	-	North America	Canada	Pond Inlet, Nunavut	When they see big, thick, fluffy, dark clouds in the direction of Arctic Bay (a hamlet about 200 km west of Pond Inlet)	-	Bad weather or rain in Pond Inlet	Simonee et al. (2021)
Clouds	-	North America	Canada	Pond Inlet, Nunavut	When they see layered clouds (three layers or thin streaks of clouds) at Bylot Island	-	Windy between Pond Inlet and Bylot Island	Simonee et al. (2021)
Clouds	-	North America	Canada	Pond Inlet, Nunavut	When clouds build up behind the mountain (Mountain Igarjuaq), it looks like smoke coming out of an	-	A few windy days are expected	Simonee et al. (2021)

					oven. When Igarjuaq has smoke like cloud or fog above it and resembles a chimney			
Clouds	-	Africa	Uganda	Rwenzori region	Dark/black/grey clouds/nimbus; appearance of clouds on Mount Rwenzori	-	Indicator for onset of rains (43.4%), 5-day forecasts (42.0%), seasonal forecasts (3.3%)	Nkuba et al. (2020)
Clouds	-	Africa	Uganda	Rwenzori region	Formation of clouds, cumulus clouds on Mount Rwenzori	-	Indicator for cessation of rains (4.4%)	Nkuba et al. (2020)
Clouds (Mununkum)	-	Africa	Ghana	Western region (Sewfi Bosomoiso community)	Cloud formation in the East	-	Indication of rainfall in the community	Ankrah, Kwapong & Boateng (2022)
Clouds (Mununkum)	-	Africa	Ghana	Western region (Jomoro community)	Cloud formation in the East	-	Indication of rainfall in the community	Ankrah, Kwapong & Boateng (2022)
Clouds (sagbona)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Dark clouds amidst strong winds	-	Rain in few hours	Nyadzi et al. (2021)

Clouds (sagbona)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Cirrostratus clouds	-	Onset of rain in few days. The thicker the clouds get, the closer the rains.	Nyadzi et al. (2021)
Clouds around the sun	-	Asia	Nepal	Kirtipur	If clouds appear around the sun at dawn	Monsoon (early June-September)	Rain will come within a week. The quantity of rain depends on the size of clouds. Thick clouds mean heavy rainfall, thin clouds mean drizzle	Poudel et al. (2022)
Clouds around the sun	-	Asia	Nepal	Kirtipur	If the sun is covered with clouds at dusk	Monsoon (early June-September)	Rain will come within three days. The quantity depends on the size of the clouds. Thick clouds mean heavy rainfall, thin clouds mean drizzle	Poudel et al. (2022)
Formation of clouds	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West	When the rain threatens, and the clouds appear red at the onset of	Onset of rainy season	Likelihood of storms during that year is higher	Jabik (2022)

				and Tempane districts)	the rainy season			
Line of clouds	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	When a 'line of clouds' (north to south) is observed in the sky at night, which divides the sky in two parts	-	The line is believed to be changing position during seasons. When the rains are about to set in, the half to the east becomes larger than the half to the west, and when the dry season gets closer, the half to the west becomes larger than the half to the east.	Jabik (2022)
Nimbus clouds (mvumi)	-	Africa	Zimbabwe	Bikita district	Mum indicates onset of good rains	-	Onset of good rains (--> be prepared for more intensive farming)	Mafongoya, Mafongoya & Mudhara (2021)
Dew	-	Africa	Uganda	Rwenzori region	Dew in the morning	-	Indicator for onset of rains	Nkuba et al. (2020)

							(0.5%), seasonal forecasts (0.2%)	
Dew	-	Africa	Uganda	Rwenzori region	No dew in the morning	-	Indicator for cessation of rains (0.7%)	Nkuba et al. (2020)
Dew	-	Africa	Zambia	Sesheke district	Absence of dew on the ground and plants in the mornings	Rainy season	Potential rains on that day	Mushimbei & Libanda (2022)
Fog (kpaandug)	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Fog	May - June	Rains will soon set in, with higher chances of a good rainfall pattern in that year	Jabik (2022)
Fog (kpaandug)	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Fog	September	Chances of rains ceasing early are higher	Jabik (2022)
Fog (paʃli)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	The appearance of fog	-	Rain in the next few hours or the next day. Mostly low rains in the form of drizzle.	Nyadzi et al. (2021)

Fog/mist	-	Africa	Uganda	Rwenzori region	Fog/mist along Mount Rwenzori, near Lake Edward	-	Indicator for onset of rains (3.3%), 5-day forecasts (2.6%), seasonal forecasts (0.7%)	Nkuba et al. (2020)
Fog/mist	-	Africa	Uganda	Rwenzori region	Fog/mist disappears on Lake Edward	-	Indicator for cessation of rains (3.5%)	Nkuba et al. (2020)
Mist	-	Africa	Uganda	Rwenzori region	No mist in the wetland	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)
Mist-covered mountains	-	Africa	South Africa	Limpopo Province (Vhembe District)	-	-	-	Kom et al. (2022)
Lightning	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (1.5%), 5-day forecasts (1.4%)	Nkuba et al. (2020)
Lightning	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Lightning accompanied by thunder repetitively occurring especially during the dry season	Dry season	Indicates the closeness of the onset of the rainy season	Nyadzi et al. (2021)

Lightning (mheni)	-	Africa	Zimbabwe	Bikita district	Lightning spells during rainy season	-	Indicates coming of dry spells	Mafongoya, Mafongoya & Mudhara (2021)
Thunder	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (4.4%), 5-day forecasts (3.1%), seasonal forecasts (0.3%)	Nkuba et al. (2020)
Thunder and lightning	-	Asia	Philippines	Mindoro Island	Thunder and lightning	-	Incoming rainy season	Ruzol, Lomente & Pulhin (2021)
Thunderstorm s	-	Africa	Nigeria	Delta state	Heavy thunderstorm s	-	Arrival of the early rain.	Ebhuoma (2020)
Frost/moistur e under stones on June 24th	-	South America	Bolivia	Umala municipality	-	June 24th	Whether the year will be wet or dry (seasonal forecast)	Gilles et al. (2022)
Frost/moistur e under stones on June 24th	-	South America	Bolivia	Ancoraimes municipality	-	June 24th	Quality of upcoming growing season (seasonal forecast)	Gilles et al. (2022)
Hazy weather	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West	Experiencing hazy weather in October	October	Setting in of the hamattan season and therefore	Jabik (2022)

				and Tempane districts)			early cessation of the rainy season	
Humidity	-	Africa	Uganda	Rwenzori region	Humid conditions	-	Indicator for onset of rains (2.9%), 5-day forecasts (1.0%), seasonal forecasts (0.2%)	Nkuba et al. (2020)
Mirage	-	North America	Canada	Pond Inlet, Nunavut	When Bylot Island appears to be much closer to Pond Inlet than usual, and they can see it very clearly	-	Windy at Bylot Island or windy between Pond Inlet and Bylot Island	Simonee et al. (2021)
Storms/hailstones	-	Africa	Uganda	Rwenzori region	Storms/hailstones	-	Indicator for seasonal forecasts (0.2%)	Nkuba et al. (2020)
Weather in other communities	-	North America	Canada	Pond Inlet, Nunavut	Igloolik is a hamlet about 400 km southwest of Pond Inlet. They know that whatever weather Igloolik has,	-	Similar weather as in Igloolik within 3 days	Simonee et al. (2021)

Rainbow	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Rainbow colours	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Rainbow	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	When there is a rainbow around the clouds for the first and second rains at the start of the rainy season	Onset of rainy season	Drought is likely to be experienced that year	Jabik (2022)
Rainbow (murarabungu)	-	Africa	Zimbabwe	Bikita district	Rainbow during rainy season	-	Coming of dry spells	Mafongoya, Mafongoya & Mudhara (2021)
Cessation of rainfall	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	When early cessation of rainfall (around September or October) is observed in a year,	-	Chances of there being early onset of the rains in the succeeding year are higher	Jabik (2022)
Rain	-	Africa	Ethiopia (central)	Oromo community	Rain started on woman's fortune day	-	It will be a good season	Mekonnen et al. (2021)
Rain	-	Africa	Ethiopia (central)	Oromo community	Rain started on horse's fortune day	-	It will rain erratically	Mekonnen et al. (2021)

Rain	-	Africa	Ethiopia (central)	Oromo community	Rain started on the *bull's fortune day*	-	Drought is expected	Mekonnen et al. (2021)
Rain	-	Africa	Ethiopia (central)	Oromo community	Rain started on elephant's fortune day	-	Heavy rain is expected	Mekonnen et al. (2021)
Rainfall	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Experiencing rainfall without heavy louds or the threat of rain	September	Rains will cease early in that year	Jabik (2022)
Rainfall onset	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	When the rains at the onset are experienced with storms	-	Likelihood that there will be an erratic and inadequate volume of rainfall in that year	Jabik (2022)
Rainfall pattern	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Experiencing frequent rainfall at the onset of the rainy season (three times a week) coupled with warm weather	-	Higher likelihood of normal rainfall during the rainy season, but cessation will be earlier than usual.	Jabik (2022)
Rainfall pattern	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West	When experiencing infrequent rains at the	-	Erratic rainfall is expected in the rainy	Jabik (2022)

				and Tempane districts)	onset of the rainy season,		season that year	
Rainfall pattern	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	If the rains fail to fall consistently for three consecutive times soon after cultivating crops	Onset of rainy season	Indicates there will be drought	Jabik (2022)
Red sky	-	Africa	Ethiopia (central)	Oromo community	Red sky at sunrise	-	Rain is expected	Mekonnen et al. (2021)
Sky	-	Africa	Uganda	Rwenzori region	Clear sky	-	Indicator for the onset of rains (8.2%), cessation of rains (15.5%), 5-day forecast (26.5%), seasonal forecast (1.1%)	Nkuba et al. (2020)
Sky	-	North America	Canada	Pond Inlet, Nunavut	When they see the sky begin to open up toward Emerson Island, after days of dark skies and bad weather (gray; snowing)	-	Good weather is on its way	Simonee et al. (2021)

Sky	-	Africa	Benin	Kandi, Glazoué & Zè commune	Behavior of sky is used in climate forecasting	-	-	Amegnaglo, Mensah-Bonsu & Anaman (2022)
Sky	-	Africa	Kenya	Tharaka South	Clear sky during full moon	-	Low rainfall to drought conditions	Mugi-Ngenga et al. (2021)
Sky	-	Africa	Zimbabwe	Limpopo Province	The moon was not covered with thin cloud and clouds (during day) were not chased away by winds	-	Below average rainfall coming rainy season	Andersson et al. (2020)
Sun	-	Africa	Kenya	Tharaka South	Glaring sun and very hot	-	Rains will begin, meaning that farmers should prepare lands to plant	Mugi-Ngenga et al. (2021)
Sun	-	Africa	Kenya	Tharaka South	Glaring sun with not much heat	-	Inadequate rains, so plant drought-resistant crops	Mugi-Ngenga et al. (2021)
Sun	-	Africa	Kenya	Tharaka South	Its movement towards the "Kianjege" mountain observed very early in the	-	Long dry spell expected, meaning that farmers should plant drought-	Mugi-Ngenga et al. (2021)

					morning (5 am). If it passes a point called "Kirikuyu" and goes beyond it		resistant crops like cassava and pigeon peas	
Sun	-	Africa	Uganda	Rwenzori region	Continuous sunshine	-	Indicator for cessation of rains (8.5%), 5-day forecasts (3.6%), seasonal forecasts (1.1%)	Nkuba et al. (2020)
Sun (Owia)	-	Africa	Ghana	Western region (Ezinlibo)	When the sun scorches with heat	-	Onset of the rains	Ankrah, Kwapong & Boateng (2022)
Cold and warm temperature (Kupisa/Kutonhora)	-	Africa	Zimbabwe	Bikita district	Extreme winter temperatures (between May and August)	May - August	Good farming season (--> be prepared for intensive farming)	Mafongoya, Mafongoya & Mudhara (2021)
Heat	-	Oceania	Fiji	Rakiraki, Gallau, Korotale & Wailevu	Heat	-	Sign of upcoming cyclone	Nakamura & Kanemasu (2022)
Heatwaves	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West	Experiencing heatwaves with lightning around March	March	Indicates higher likelihood of the early	Jabik (2022)

				and Tempane districts)			onset of the rainy season	
Hot weather (walgu be-ni)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	The high temperature that causes profuse sweating	March	Onset of rains in few weeks	Nyadzi et al. (2021)
Hot weather (walgu be-ni) & humidity	-	Africa	Ghana	Kumbungu district (Northern Ghana)	High temperatures and humidity	Rainy season	Fain in the next hours or day. Rainfall is expected the next day if temperatures are high during the night such that one sweats profusely and unable to sleep.	Nyadzi et al. (2021)
Temperature	-	Africa	Malawi	Salima, Mangochi, and Zomba districts	When you experience high temperatures in June, it usually means that there will be low temperatures in October	June	Inadequate rainfall	Streefkerk et al. (2022)
Temperature	-	Africa	Malawi	Salima, Mangochi, and	When July is sunny and hot	July	Drought	Streefkerk et al. (2022)

				Zomba districts				
Temperature	-	Africa	Malawi	Salima, Mangochi, and Zomba districts	When it is cold in October and November	October - November	Dry spell is expected	Streefkerk et al. (2022)
Temperature	-	Africa	Malawi	Salima, Mangochi, and Zomba districts	When it is hot	October - November	It will rain	Streefkerk et al. (2022)
Temperature	-	Africa	Ghana	Volta region (Zovie community)	Extremely high temperature accompanied by cool wind	-	Onset of rains; likely to rain within a day to a week	Ankrah, Kwapong & Boateng (2022)
Temperature	-	Africa	Ghana	Volta region (Dekpor-Horme)	Extremely high temperature accompanied by cool wind	-	Imminent rains	Ankrah, Kwapong & Boateng (2022)
Temperature	-	Africa	Ghana	Northern region (Mogneigu community)	Extremely high temperature (more than normal) during the day	-	Rainfall at night	Ankrah, Kwapong & Boateng (2022)
Temperature	-	Africa	Uganda	Rwenzori region	Coldness in the morning	-	Indicator for onset of rains (1.4%), cessation of rains (3.7%), 5-day forecasts (1.9%), seasonal	Nkuba et al. (2020)

							forecasts (0.2%)	
Temperature	-	Africa	Uganda	Rwenzori region	Coldness at night	-	Indicator for cessation of rains (0.1%)	Nkuba et al. (2020)
Temperature	-	Africa	Uganda	Rwenzori region	Heat at night	-	Indicator for onset of rains (2.1%), cessation of rains (0.3%), 5-day forecasts (3.7%), seasonal forecasts (0.1%)	Nkuba et al. (2020)
Temperature	-	Africa	Ethiopia (central)	Oromo community	Temperature of the day become hotter	-	It is going to rain soon	Mekonnen et al. (2021)
Temperature	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	-	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Temperature	-	Africa	South Africa	Limpopo Province	High temperature at the beginning of summer	Summer	High probability of rainfall	Rankoana (2022)
Temperature/ heat	-	Africa	Uganda	Rwenzori region	Increase in temperature/ heat	-	Indicator for the onset of rains (5.7%), cessation of	Nkuba et al. (2020)

							rains (2.1%), 5-day forecast (4.1%), seasonal forecast (0.7%)	
Bundibugyo winds	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.1%), cessation of rains (0.1%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Bunyoro winds	-	Africa	Uganda	Rwenzori region	Wind blows from west to east	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)
Butuku winds	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.2%), cessation of rains (0.1%)	Nkuba et al. (2020)
Cold winds	-	Africa	Uganda	Rwenzori region	Cold wind	-	Indicator for onset of rains (2.0%), cessation of rains (2.0%), 5-day forecasts (2.6%), seasonal forecasts (0.4%)	Nkuba et al. (2020)

Congo winds	-	Africa	Uganda	Rwenzori region	Wind blows from west to east	-	Indicator for onset of rains (2.8%), cessation of rains (1.2%), 5-day forecasts (1.7%), seasonal forecasts (0.1%)	Nkuba et al. (2020)
Hot winds	-	Africa	Uganda	Rwenzori region	Hot wind	-	Indicator for onset of rains (1.5%), cessation of rains (0.4%), 5-day forecasts (2.0%), seasonal forecasts (0.1%)	Nkuba et al. (2020)
Ihunga	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.3%)	Nkuba et al. (2020)
Ituri winds	-	Africa	Uganda	Rwenzori region	Wind blows from west to east	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)
Kasambura winds	-	Africa	Uganda	Rwenzori region	Wind blows from south to north	-	Indicator for onset of rains (0.3%), cessation of rains (1.4%)	Nkuba et al. (2020)

Kinjura	-	Africa	Uganda	Rwenzori region	Wind blows from north to south	-	Indicator for onset of rains (0.2%), cessation of rains (0.4%), 5-day forecasts (0.2%), seasonal forecasts (0.3%)	Nkuba et al. (2020)
Kitagweda	-	Africa	Uganda	Rwenzori region	Wind flows from east to west	-	Indicator for onset of rains (0.2%), cessation of rains (0.2%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Lake Albert wind	-	Africa	Uganda	Rwenzori region	Wind blows from west to east	-	Indicator for onset of rains (0.8%), cessation of rains (0.4%), 5-day forecasts (0.3%)	Nkuba et al. (2020)
Lake George winds	-	Africa	Uganda	Rwenzori region	Wind from Lake George to inland	-	Indicator for onset of rains (0.1%), cessation of rains (0.2%), 5-day	Nkuba et al. (2020)

							forecasts (0.2%)	
Musasi	-	Africa	Uganda	Rwenzori region	Wind blows from west to east	-	Indicator for onset of rains (9.7%), cessation of rains (3.0%), 5-day forecasts (2.9%), seasonal forecasts (1.3%)	Nkuba et al. (2020)
Muzizi River	-	Africa	Uganda	Rwenzori region	Blows from west to east	-	Indicator for onset of rains (1.5%), cessation of rains (0.4%), 5-day forecasts (0.8%), seasonal forecasts (0.1%)	Nkuba et al. (2020)
Ndowa	-	Africa	Uganda	Rwenzori region	Wind blows from east to west	-	Indicator for onset of rains (4.1%), cessation of rains (11.4%), 5-day forecasts (3.2%), seasonal	Nkuba et al. (2020)

							forecasts (0.8%)	
Rwenzori wind	-	Africa	Uganda	Rwenzori region	Wind from the mountain	-	Indicator for onset of rains (0.3%), 5-day forecasts (0.3%)	Nkuba et al. (2020)
Tooro winds	-	Africa	Uganda	Rwenzori region	Wind blows from east to west	-	Indicator for onset of rains (0.2%), cessation of rains (0.4%)	Nkuba et al. (2020)
Wabubo	-	Africa	Uganda	Rwenzori region	Wind blows from west to east	-	Indicator for onset of rains (0.4%)	Nkuba et al. (2020)
Wabubo	-	Africa	Uganda	Rwenzori region	Wind blows from west to east	-	Indicator for onset of rains (0.7%), cessation of rains (0.3%), 5-day forecasts (0.1%), seasonal forecasts (0.1%)	Nkuba et al. (2020)
Whirlwind	-	Africa	Uganda	Rwenzori region	Whirlwind	-	Indicator for onset of rains (1.2%), cessation of rains (1.1%), 5-day forecasts	Nkuba et al. (2020)

							(0.2%), seasonal forecasts (0.1%)	
Wind	-	Africa	Nigeria	Delta state	Strong winds	-	Onset of the rainy season	Ebhuoma (2020)
Wind	-	Africa	Uganda	Rwenzori region	Wind blows from west to east; wind blows from east to west	-	Indicator for onset of rains (17.3%), cessation of rains (10.4%), 5-day forecasts (4.7%), seasonal forecasts (1.7%)	Nkuba et al. (2020)
Wind	-	Africa	Kenya	Kitui Central	A very strong wind blowing in circles and repeatedly for some days	-	Rains are just about to begin	Mugi-Ngenga et al. (2021)
Wind	-	Asia	Nepal	Kirtipur	Wind blowing form east to west	Summer	Onset of rainy season	Poudel et al. (2022)
Wind	-	Asia	Nepal	Kirtipur	Wind blowing from west to east	End of summer	Cessation of rainy season	Poudel et al. (2022)
Wind	-	Africa	Ethiopia	Gomole district	When a dusty fast wind blows from west to east	-	Imminent rains that likely falls within days	Dejene & Yetebarek (2022)

Wind	-	Africa	Ethiopia	Gomole district	When fiercely wind continuously blows from east to west	Near onset of rainy season	Drought or delay in the imminent rainy season	Dejene & Yetebarek (2022)
Wind	-	Africa	Ghana	Northern region (Yendi Municipality)	When the temperature in the room at night is unbearable but is then turned into a cool breeze	Dry season	It will rain	Adanu, Abole & Gbedemah (2022)
Wind	-	Asia	Philippines	Samar province, municipality of Basey	Mamanwas believe there are six origins of the wind. When the Kanaway wind blows	September - January	Windy and stormy weather, risk of typhoon (--> time to prepare raw materials for *kurob* and harvest of climate-resistant crops)	Cuaton & Su (2020)
Wind	-	Asia	Philippines	Samar province, munipality of Basey	Mamanwas believe there are six origins of the wind. When the *Kabunghan blows*	September - December	Sunny and windy weather, no hazards expected	Cuaton & Su (2020)

Wind	-	Asia	Philippines	Samar province, munipality of Basey	Mamanwas believe there are six origins of the wind. When the *Salatan* blows	March - April	Sunny with low wind, no hazards expected (--> preparation of rice fields)	Cuaton & Su (2020)
Wind	-	Asia	Philippines	Samar province, munipality of Basey	Mamanwas believe there are six origins of the wind. When the *Amihan* blows	September - January	Rainy weather, floods and landslides are hazards	Cuaton & Su (2020)
Wind	-	Asia	Philippines	Samar province, munipality of Basey	Mamanwas believe there are six origins of the wind. When the *Habagat* blows	June - August	Rainy weather, floods and landslides are hazards (--> wind is strongest during August, hence harvesting of rice begins late July to early August)	Cuaton & Su (2020)
Wind	-	Asia	Philippines	Samar province, munipality of Basey	Mamanwas believe there are six origins of the wind. When *Amihan* and *Habagat* are blowing	September - January	Rainy weather, floods; low chances of typhoon	Cuaton & Su (2020)

Wind	-	Asia	Philippines	Samar province, munipality of Basey	Mamanwas believe there are six origins of the wind. When *Salatan* and *Timog* are blowing	February - May	Sunny and dry weather, dry spells and possible forest fires (--> planting season of rice)	Cuaton & Su (2020)
Wind	-	Asia	Philippines	Samar province, munipality of Basey	Mamanwas believe there are six origins of the wind. When *Kanaway* and Kabunghan are blowing	September - December	Stormy, windy, rainy weather; floods, landslides and typhoons are hazards (--> time to prepare raw materials for *kurob* and harvest climate-resistant crops)	Cuaton & Su (2020)
Wind	-	Africa	Benin	Kandi, Glazoué & Zè commune	Behaviour of wind is used in climate forecasting	-	-	Amegnaglo, Mensah-Bonsu & Anaman (2022)
Wind	-	Africa	South Africa	Limpopo Province	Strong winds	-	Reduced rainfall probability	Rankoana (2022)
Wind (cold)	-	Africa	Malawi	Salima, Mangochi, and	When there are cold winds	October - November	Rains will delay	Streefkerk et al. (2022)

				Zomba districts				
Wind (Mhepo)	-	Africa	Zimbabwe	Bikita district	Wind blowing from east to west	-	Imminent rains (--> get prepared for cropping)	Mafongoya, Mafongoya & Mudhara (2021)
Wind (Mhepo)	-	Africa	Zimbabwe	Bikita district	Wind blowing from west to east	-	Indicates dry spells	Mafongoya, Mafongoya & Mudhara (2021)
Wind (pohim)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Strong winds from west to east	-	Rain the next day	Nyadzi et al. (2021)
Wind (pohim)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Swirling winds at high frequency	Dry season	Onset of rains (good rainy season)	Nyadzi et al. (2021)
Wind direction	-	Africa	Ghana	Wa West District	Direction of wind	-	Indicates change in season	Sullo et al. (2020)
Wind direction	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	-	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Wind direction	-	Africa	Zambia	Sesheke district	Continuous wind flow of stable easterlies or north-easterlies	Rainy season	Rainfall before the end of the day or within 3 days	Mushimbei & Libanda (2022)

Wind direction	-	Africa	Malawi	Salima, Mangochi, and Zomba districts	When they have Mwera winds blowing heavily (Mwera winds block the North-easterly wind)	October - November	Dry spell is expected	Streefkerk et al. (2022)
Wind direction	-	Africa	Malawi	Salima, Mangochi, and Zomba districts	North Easterly winds	October - November	Sign of good rains	Streefkerk et al. (2022)
Wind direction	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	North-east to south-west winds	October - November	Cessation of rainy season	Jabik (2022)
Wind direction	-	Africa	South Africa	Limpopo Province	1. Wind blowing in all directions, 2. Winds blowing from the south-east	-	1. Good rainfall season, 2. Drought	Rankoana (2022)
Wind direction	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	The south-west to north-east winds. It is believed that the south-west to north-east winds lead to accumulation	March - April	Onset of rainy season	Jabik (2022)

					of clouds in the east, which result in rain.			
Wind intensity/duration	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	The intensity and duration of winds (south-west) before the first rains	-	Heavy rains in a year are associated with less wind.	Jabik (2022)
Wind movement	-	Africa	South Africa	Limpopo Province (Vhembe District)	-	-	-	Kom et al. (2022)
Wind pattern	-	Asia	India	Tangkhul Naga community (Northeast India)	A shift in wind pattern	Spring (*Mayo season*)	Indicates the impending arrival of heavy rain or hailstorms	Varah & Varah (2022)
Wind speed	-	Africa	Malawi	Salima, Mangochi, and Zomba districts	When there is little wind	September and October	Indicates that rain will be on time	Streefkerk et al. (2022)
Wind speed	-	Africa	Malawi	Salima, Mangochi, and Zomba districts	When it is windy	September and October	Indicates that chances of good rains are minimal	Streefkerk et al. (2022)
Wind speed	-	Africa	Malawi	Salima, Mangochi, and Zomba districts	Heavy winds (+ whirlwinds)	October - November	Erratic rains in that season, especially when also experiencing whirlwinds	Streefkerk et al. (2022)

Wind speed	-	Asia	Nepal	Thapuwa & Bikri (Gulariya municipality, Bardiya district)	Used to predict extreme climate phenomena, such as excessive rainfall and drought	-	-	Chaudhary et al. (2021)
Winds	-	South America	Bolivia	Umala municipality	-	March - November	Frosts and hail (short-term forecast)	Gilles et al. (2022)
Winds	-	South America	Bolivia	Ancoraimes municipality	-	March - December	Frost and hail (short-term forecast)	Gilles et al. (2022)
Wind direction	-	Asia	Nepal	Thapuwa & Bikri (Gulariya municipality, Bardiya district)	Used to predict extreme climate phenomena, such as excessive rainfall and drought	-	-	Chaudhary et al. (2021)

X.A.4 – Multiple

Table A.X - 13 Rainfall indicators based on multiple categories.

Indicator name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Flowering time/animal gestation period	Asia	Indonesia	Jawa	When it is the animal gestation period and	-	Indicates shifting seasons, from rainy to dry	Zaki et al. (2020)

				flowering time (of e.g., Kapok trees), and spring water dries up			

X.A.5 – Plants

Table A.X - 14 Rainfall indicators based on plants.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Acacia	-	Africa	Uganda	Rwenzori region	Flowering; bring new shoots; shade leaves	-	Indicator for onset of rains (2.0%), cessation of rains (1.8%), 5-day forecasts (0.3%)	Nkuba et al. (2020)
Acacia albida/Winter Thorn (Muhunga)	Faidherbia albida	Africa	Zambia	Sesheke district	When the Winter Thorn flowers between August - October	August - October	High likelihood of above-average rainfall in the forthcoming rainy season	Mushimbei & Libanda (2022)
Acacia albida/Winter Thorn (Muhunga)	Faidherbia albida	Africa	Zambia	Sesheke district	When the Winter Thorn has little or no flowers in the period August - October	-	Increased probability of experiencing prolonged dry spells during rainy season	Mushimbei & Libanda (2022)

Acacia plant	-	Africa	South Africa	Limpopo Province	Flowering of the acacia plant, good quality of flowers	-	Good rainy season	Rankoana (2022)
Alfilerrillo	Erodium cicutarium	South America	Argentina	Central-north region of Chubut	Absence of *verdín*	-	Dry year (short-term change)	Castillo, Rostagno & Ladio (2020)
Alfilerrillo	Erodium cicutarium	South America	Argentina	Central-north region of Chubut	Roots uncovered	-	Little fodder in the countryside (long-term change)	Castillo, Rostagno & Ladio (2020)
Algarrobillo	Prosopis denudans	South America	Argentina	Central-north region of Chubut	Absence of fruit of this plant	-	Dry year (short-term change)	Castillo, Rostagno & Ladio (2020)
Aloe plant (Gavakava)	Aloe vera	Africa	Zimbabwe	Bikita district	Heavy flowering and seeds	-	Good season (--> be prepared for bumper harvest season)	Mafongoya, Mafongoya & Mudhara (2021)
Aloe plant (Gavakava)	Aloe vera	Africa	Zimbabwe	Bikita district	Scattered flowers and seeds	-	Drought	Mafongoya, Mafongoya & Mudhara (2021)
Amañoke	Ombrophytum subterraneum	South America	Bolivia	Umala municipality	-	December - February	Crop forecast (short-term)	Gilles et al. (2022)
Assiflora edulis (sitāpor)	-	Asia	India	Tangkhul Naga community (Northeast India)	The blooming of sitapor	April	Indicates the time for plucking cabbage, mustard	Varah & Varah (2022)

							leaves, Centella asiatica and Houttuynia cordata)	
Bamboo tree	-	Africa	Uganda	Rwenzori region	Flowering	-	Indicator for cessation of rains (0.2%)	Nkuba et al. (2020)
Bamboo buds	-	Asia	Indonesia	Jawa	When bamboo buds appear	-	Beginning of the dry season	Zaki et al. (2020)
Bamboo plant	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	Bamboo shoots (not yet widely) become longer/bigger than the parent	-	Plenty of rainy days in 1 year	Limpo et al. (2022)
Banana	-	Africa	Uganda	Rwenzori region	Flowering; harvests increase	-	Indicator for cessation of rains (0.1%)	Nkuba et al. (2020)
Banana plant	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	Banana petals fall and face up	-	Plenty of rainy days in 1 year	Limpo et al. (2022)
Baobab tree	Adansonia digitate	Africa	Ghana	Northern region (Yendi Municipality)	As soon as flowers and new shot of leaves start to appear on the baobab tree	Towards the end of harmattan (dry) season	In matter of weeks rainfall will begin	Adanu, Abole & Gbedemah (2022)

					and its branches			
Baobab tree (tuhi)	Adansonia digitate	Africa	Ghana	Kumbungu district (Northern Ghana)	Baobab tree begins to flower and generates new leaves	-	Onset of rainfall. The more the flowers the season is predicted to be wetter than normal	Nyadzi et al. (2021)
Baobab tree (Tuick)	-	Africa	Ghana	Northern region (Zabzugu community)	When the tree grows fresh leaves	-	Onset of rains	Ankrah, Kwapong & Boateng (2022)
Barba de chivo	-	South America	Argentina	Central-north region of Chubut	Absence of new shoots of this plant	-	Dry year (short-term change)	Castillo, Rostagno & Ladio (2020)
Barba de chivo	Prosopisdastru m globosum	South America	Argentina	Central-north region of Chubut	Exposed roots	-	Drought (long-term change)	Castillo, Rostagno & Ladio (2020)
Bark cloth tree	Ficus natalensis	Africa	Uganda	Rwenzori region	Flowering; shade leaves	-	Indicator for onset of rains (0.7%), cessation of rains (1.7%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Behavior of certain plants - unfurling of new leaves on baobab tree	-	Africa	South Africa	Limpopo Province (Vhembe District)	-	-	-	Kom et al. (2022)

Bird plum/brown ivory (Muzinzila)	Berchemia discolor	Africa	Zambia	Sesheke district	Bird plum has lots of fruits	October - November	Signals a potential delay in the onset of the rainy season	Mushimbei & Libanda (2022)
Bisduga	Kirkia burgeri	Africa	Ethiopia	Gomole district	When the leaves profoundly turn into green	May	Good rainfall is predicted for imminent *ganna* rainy season	Dejene & Yetebarek (2022)
Burquqe	Acacia nilotica	Africa	Ethiopia	Gomole district	The plant blossoms	-	Approaching *ganna* rainy season	Dejene & Yetebarek (2022)
Burra	Acacia goetzei	Africa	Ethiopia	Gomole district	When the leaves profoundly turn into green	May	Good rainfall is predicted for imminent *ganna* rainy season	Dejene & Yetebarek (2022)
Canthium burtti (Mubilo)	Afrocanthium pseudorandii	Africa	Zambia	Sesheke district	Fruition of Canthium burtii	October - November	A generally poor rainy season is looming	Mushimbei & Libanda (2022)
Cassava leaves	Manihot esculenta	Africa	Nigeria	Delta state	Cassava leaves becomes fresh.	-	Arrival of the rainy season.	Ebhuoma (2020)
Ceiba (Ya'ax che' (Maya))	Ceiba pentandra (L.) Gaerth	North America	Mexico	Yucatán Peninsula	The amount of fruit on the ceiba trees	March - April	Good (trees with a lot of fruits) or bad (trees few fruits) harvest	Camacho-Villa et al. (2021)
Cocoa	-	Africa	Uganda	Rwenzori region	Flowering	-	Indicator for onset of rains (1.4%),	Nkuba et al. (2020)

							cessation of rains (0.1%), 5-day forecasts (0.2%)	
Coffee	-	Africa	Uganda	Rwenzori region	Flowering; ripening of berries	-	Indicator for onset of rains (6.9%), cessation of rains (0.9%), 5-day forecasts (0.8%), seasonal forecasts (0.6%)	Nkuba et al. (2020)
Cola piche	Nassauvia glomerulosa	South America	Argentina	Central-north region of Chubut	Green plant	-	Wet year (short-term change)	Castillo, Rostagno & Ladio (2020)
Dendrobium denudans (shāilengwon)	-	Asia	India	Tangkhul Naga community (Northeast India)	Blooming of this plant	Summer	Time for transplantatio n of paddy	Varah & Varah (2022)
Dhaddacha	Acacia tortilis	Africa	Ethiopia	Gomole district	The plant blossoms	-	Approaching *ganna* rainy season	Dejene & Yetebarek (2022)
Dialium angolense (Muhumani)	-	Africa	Zambia	Sesheke district	Tree bears more fruits than usual	September and October	High likelihood above-average rainfall with very short and infrequent dry spells	Mushimbei & Libanda (2022)

Earpod trees (Pich (Maya), parota (Spanish))	Enteroblum cyclocarpum (Jacq.) Griseb	North America	Mexico	Yucatán Peninsula	The amount of fruit on earpod trees	March - April	Good (trees with a lot of fruits) or bad (trees few fruits) harvest	Camacho-Villa et al. (2021)
Fig tree (Muonde)	Fiscus carica	Africa	Zimbabwe	Bikita district	Shooting brownish leaves	-	Imminent rains (--> be prepared for cropping)	Mafongoya, Mafongoya & Mudhara (2021)
Fine grasses	Carex sp., Eleocharis sp., Hordeum comosum, Bromus sp., Elymus sp., Nassella tenuis, Piptochaetium sp., Poa ligularis, Poa lanuginosa, Schismus barbatus	South America	Argentina	Central-north region of Chubut	Decrease in amount of grass	-	Drought (long-term change)	Castillo, Rostagno & Ladio (2020)
Fish Fuddle (Jahin (Maya), Jabin (Spanish))	Piscidia piscipula L.	North America	Mexico	Yucatán Peninsula	The number of fruits and leaves	January - February	Good (too many fruits and few leaves) harvest or bad harvest (too many leaves and few fruits)	Camacho-Villa et al. (2021)

Flamboyant tree	-	Africa	Ghana	Volta region (Agotime Ziope District)	The time of flowering of the flamboyant tree	-	Indicates the onset of the rains	Ankrah, Kwapong & Boateng (2022)
Flower and fruit production of rural trees	-	Africa	South Africa	Limpopo Province (Vhembe District)	-	-	-	Kom et al. (2022)
Fruit trees	-	Africa	Uganda	Rwenzori region	Flowering	-	Indicator for onset of rains (0.9%), cessation of rains (0.1%), 5-day forecasts (0.2%)	Nkuba et al. (2020)
Fruit-bearing trees	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	The bearing of fruits of the shea tree, dawadawa tree and the black and yellow berries. Well-fruited trees	-	Quality of the fruits indicates the likelihood of good crop yield that year	Jabik (2022)
Grass	-	Africa	Uganda	Rwenzori region	Withering; drying of grass	-	Indicator for cessation of rains (0.4%)	Nkuba et al. (2020)
Grass	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West	Flowering of grasses	-	Indication the dry season is starting	Jabik (2022)

				and Tempane districts)				
Grasses	Festuca pallescens, Pappostipa humilis, Pappostipa speciosa	South America	Argentina	Central-north region of Chubut	Yellowed grass	-	Drought (long-term change)	Castillo, Rostagno & Ladio (2020)
Guava fruit	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	Significant amount of guava fruit grows in the forest and the fruits are not attacked by pests	-	Rice will be harvested safely without risk of pests	Limpo et al. (2022)
Guhunga tree	-	Africa	Zimbabwe	Bikita district	Heavy flowering	-	Good rains (--> be prepared for bumper harvests season)	Mafongoya, Mafongoya & Mudhara (2021)
Handada	Entada leptostachya	Africa	Ethiopia	Gomole district	When the leaves profoundly turn into green	May	Good rainfall is predicted for imminent *ganna* rainy season	Dejene & Yetebarek (2022)
Handada, Bisduga, Burra, Rukessa	-	Africa	Ethiopia	Gomole district	Unusual tumbling and drying of these flora before their plentifully maturing and	-	Drought incidence in the imminent season	Dejene & Yetebarek (2022)

					blossoming period			
Harbu' tree	-	Africa	Ethiopia (central)	Oromo community	Harbu tree started to flushing leaves	-	Rainfall is expected in a few days	Mekonnen et al. (2021)
Junquillo	Juncus balticus	South America	Argentina	Central-north region of Chubut	Absence of grass	-	Drought (long-term change)	Castillo, Rostagno & Ladio (2020)
Kúa	Satureja boliviana	South America	Bolivia	Ancoraimes municipality	-	August - November	Planting time, frost likelihood and production levels (seasonal forecast)	Gilles et al. (2022)
Lantana camara	-	Africa	Uganda	Rwenzori region	Withering	-	Indicator for cessation of rains (0.1%)	Nkuba et al. (2020)
Laq'u (Alga)	Chlorophyceae	South America	Bolivia	Ancoraimes municipality	-	September - November	Frost likelihood and production levels (mid-term and seasonal forecast)	Gilles et al. (2022)
Leaves	-	Asia	Indonesia	Jawa	When leaves start to fall	-	Beginning of the dry season	Zaki et al. (2020)
Local trees	-	Africa	Ghana	Wa West District	Flowering and fruiting of shea, dawadawa, baobab, "gutiir" and	-	Indicates the beginning of the wet season and the appropriate	Sullo et al. (2020)

					the "donlar" tree		time to start farming	
Local trees (e.g., Baobab, Shea nut, Dawadawa)	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Fruiting of local trees	-	When the tree starts to fruit, the rainfall season is imminent	Baffour-Ata et al. (2021)
Mahogany tree (Mukamba tree)	Afzelia qunzensis	Africa	Zimbabwe	Bikita district	Heavy flowering	-	Good harvests	Mafongoya, Mafongoya & Mudhara (2021)
Mahogany tree (Mukamba tree)	Afzelia qunzensis	Africa	Zimbabwe	Bikita district	With less flowering	-	(--> be prepared for droughts)	Mafongoya, Mafongoya & Mudhara (2021)
Mango or tamarin	-	Oceania	Fiji	Rakiraki, Gallau, Korotale & Wailevu	Mango or tamarin growing off season	-	Sign of upcoming cyclone	Nakamura & Kanemasu (2022)
Mango plant	-	Asia	Indonesia	South Sulawesi Province (Bugis-Makassar tribe)	Mango plants bear fruit twice a year	-	Plenty of rainy days in 1 year	Limpo et al. (2022)
Mango tree	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Flowering of the mango tree	November	Dry season will soon set in	Jabik (2022)

Mango tree	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Flowering and fruiting of mango tree	Rainy season (June/July)	Likelihood of floods that year	Jabik (2022)
Mango tree	Mangifera indica	Africa	Ghana	Northern region (Yendi Municipality)	When mango trees start flowering and bearing little fruits	-	Impending rainfall. Some farmers believe the more fruit, the more rain will fall. The size of the fruits also determines the amount of rainfall in a season.	Adanu, Abole & Gbedemah (2022)
Markhamia lutea	Markhamia lutea	Africa	Uganda	Rwenzori region	Flowering	-	Indicator for onset of rains (0.1%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Motoma tree	-	Africa	Zimbabwe	Limpopo Province	1. Many fruits and shoots on the Motoma tree, 2. Normal amount of fruit	-	1. Above average rainfall coming rainy season, 2. Normal rainfall amount coming rainy season	Andersson et al. (2020)

Mugwort (maharnā) and smartweed (sirsā)	-	Asia	India	Tangkhul Naga community (Northeast India)	Blooming of these plants	Autumn	Prolonged rainfall just before harvest	Varah & Varah (2022)
Mukwakwa tree	Sclerocarya birrea	Africa	Zimbabwe	Bikita district	Profuse fruiting of the mukwakwa tree	-	Severe drought (--> conserve food and collect more fruits as food reserves)	Mafongoya, Mafongoya & Mudhara (2021)
Munhengeni tree	Ximenia caffra	Africa	Zimbabwe	Bikita district	Profuse fruiting	-	Good rains (--> prepare for bumper harvest)	Mafongoya, Mafongoya & Mudhara (2021)
Mupani tree	Colophosperm um mopane	Africa	Zimbabwe	Bikita district	Shooting of brownish leaves	-	Imminent rains (--> be prepared for cropping)	Mafongoya, Mafongoya & Mudhara (2021)
Mushumha tree	mespiliferims	Africa	Zimbabwe	Bikita district	Heavy fruiting	-	Good season	Mafongoya, Mafongoya & Mudhara (2021)
Muswati tree	Dalbergiella nyasae	Africa	Zimbabwe	Bikita district	Heavy flowering	-	Good season (--> good season for cow peas and bumper harvest)	Mafongoya, Mafongoya & Mudhara (2021)
Mutuva tree	Kirurite mucugucugu	Africa	Zimbabwe	Bikita district	Profuse flowering	-	Good rains	Mafongoya, Mafongoya & Mudhara (2021)

Muunze tree	Brachystegia glaucescens	Africa	Zimbabwe	Bikita district	Shooting new leaves	-	Imminent rain (--> be prepared for cropping)	Mafongoya, Mafongoya & Mudhara (2021)
Muunze tree	Brachystegia glaucescens	Africa	Zimbabwe	Bikita district	Maintaining green leaves	-	Good rains (--> be prepared for bumper harvest)	Mafongoya, Mafongoya & Mudhara (2021)
Muuyu tree	Adansonia digitata	Africa	Zimbabwe	Bikita district	Heavy flowering	-	Good season	Mafongoya, Mafongoya & Mudhara (2021)
Neem	-	Africa	Uganda	Rwenzori region	Shade leaves; bring new shoots and leaves	-	Indicator for onset of rains (0.2%), cessation of rains (0.2%)	Nkuba et al. (2020)
Palm trees	Arecaceae	Asia	Vietnam	Quang Nam province	When the local Palm trees are seen to bear more than a typical amount of fruit	-	Droughts over the next year are to be prevised	Van Huynh et al. (2020)
Parinari curatellifolia (Mubula)	-	Africa	Zambia	Sesheke district	Tree bears more fruits than usual	September and October	High likelihood above-average rainfall with very short and infrequent dry spells	Mushimbei & Libanda (2022)
Pastures	-	Africa	Uganda	Rwenzori region	Change from green to yellowish	-	Indicator for cessation of rains (0.1%)	Nkuba et al. (2020)

Peach plant (mayāngtheirong)	-	Asia	India	Tangkhul Naga community (Northeast India)	When the plant blooms	Spring (*Mayo* season)	Time to sow seeds such as maize, pumpkin, cucumber, garden egg	Varah & Varah (2022)
Phuscalla	Opuntia boliviana Salm-Dick	South America	Bolivia	Umala municipality	-	August 15 - October 15	Planting time and type of year (seasonal forecast)	Gilles et al. (2022)
Phuscalla	Opuntia boliviana Salm-Dick	South America	Bolivia	Ancoraimes municipality	-	August 15 - September 15	Planting time and production levels (mid-term seasonal forecast)	Gilles et al. (2022)
Pinguica (Beek (Maya), falso roble (Spanish))	Ehretia tinifolia L.	North America	Mexico	Yucatán Peninsula	If it flowers in April and drops its flowers	April	Bad harvest	Camacho-Villa et al. (2021)
Pinguica (Beek (Maya), falso roble (Spanish))	Ehretia tinifolia L.	North America	Mexico	Yucatán Peninsula	If it flowers in May	May	A late planting will give a good harvest	Camacho-Villa et al. (2021)
Pinguica (Beek (Maya), falso roble (Spanish))	Ehretia tinifolia L.	North America	Mexico	Yucatán Peninsula	In Quintana Roo, if the tree flowers in April and keeps its leaves	April	The milpa will have too many weeds	Camacho-Villa et al. (2021)
Pinguica (Beek (Maya),	Ehretia tinifolia L.	North America	Mexico	Yucatán Peninsula	In Quintana Roo, if the tree flowers in	April	The milpa will have few weeds	Camacho-Villa et al. (2021)

falso roble (Spanish))					April and loses its leaves			
Plant buds appearing	-	Asia	Nepal	Kirtipur	1. Good buds appearing earlier on the plants, 2. Weak buds appearing late	-	1. Rain will be good and begin to fall earlier, 2. Low rain and it will be delayed	Poudel et al. (2022)
Plant flower	-	Africa	Ethiopia	Burkitu watershed	Flowering and leaf shading of the tree can be attached to seasons	-	-	Guye, Legesse & Mohammed (2022)
Plants	-	Africa	Ghana	Wa West District	Flowering of plants	-	Indicates the start of the rainy season	Sullo et al. (2020)
Plants	-	Africa	Ethiopia (eastern)	Somali community	When invasive plants appear more abundant and occupy large areas; death and/or reduction in the number of some plants and others may grow with thorny and small leaves, and fodder plants decreased	-	Coming season will be bad. If the opposite of the signal occurs, it indicates a good season	Mekonnen et al. (2021)

Plants	-	Africa	Ghana	Northern region (Yendi Municipality)	The appearance of new leaves and flowers on plants	December - January	Rain is near	Adanu, Abole & Gbedemah (2022)
Plants (e.g., Bean pod tree)	-	Africa	Ghana	Gia, Gaani and Nyangua (3 communities in Upper East Region)	Flowering of certain plants	-	Used to predict rainfall	Baffour-Ata et al. (2021)
Pyrus pashia flowers (kapāiwon)	-	Asia	India	Tangkhul Naga community (Northeast India)	Fresh leaves sprouting	Spring (*Mayo s*eason)	Time to sow seeds such as maize, pumpkin, cucumber, garden egg	Varah & Varah (2022)
Q'uta	Junellia minima	South America	Bolivia	Umala municipality	-	October 15 - December 5	Planting time and type of year (seasonal forecast)	Gilles et al. (2022)
Q'uta	Junellia minima	South America	Bolivia	Ancoraimes municipality	-	October 15 - December 5	Planting times and production levels (mid-term and seasonal forecast)	Gilles et al. (2022)
Qariwa o Wacha	Senecio clivicola	South America	Bolivia	Ancoraimes municipality	-	August - September	Planting time, frost likelihood and production levels	Gilles et al. (2022)

							(seasonal forecast)	
Rain tree (Mupanda)	Philenoptera violacea	Africa	Zimbabwe	Bikita district	Heavy flowering	-	Good season (--> prepare for bumper harvest and a successful maize growing season)	Mafongoya, Mafongoya & Mudhara (2021)
Reeds, flowers, or fruits	-	Oceania	Fiji	Rakiraki, Gallau, Korotale & Wailevu	Reeds, flowers, or fruits (particularly breadfruits) growing in abundance	-	Sign of upcoming cyclone	Nakamura & Kanemasu (2022)
Rubber trees	Ficus elastic decora	Africa	Nigeria	Delta state	Flowering of rubber trees	-	Onset of the early rains.	Ebhuoma (2020)
Rukessa	Combretum molle	Africa	Ethiopia	Gomole district	When the leaves profoundly turn into green	May	Good rainfall is predicted for imminent *ganna* rainy season	Dejene & Yetebarek (2022)
Sank'ayu	Lobivia caespietosa J. Porpus	South America	Bolivia	Ancoraimes municipality	-	August - December	Planting time and production levels (mid-term forecast)	Gilles et al. (2022)
Sausage tree (Mumveva)	Kigelia pinnata africana	Africa	Zimbabwe	Bikita district	Heavy flowering	-	Be prepared for bumper harvests	Mafongoya, Mafongoya & Mudhara (2021)

Schima wallichii (mashuithei), Meyna spinosa (theibithei) and Rhododendron arboretum (kokluiwon)	-	Asia	India	Tangkhul Naga community (Northeast India)	Flowering of these plants	May	Indicates the time for clearing the weeds and ploughing the field	Varah & Varah (2022)
Shea tree (Tan)	-	Africa	Ghana	Northern region (Mogneigu community)	Excessive fruiting of the shea tree	-	Rainfall	Ankrah, Kwapong & Boateng (2022)
Shea tree, dawadawa tree, black and yellow berry trees	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Sprouting of leaves and flowering of plants like the shea tree, dawadawa tree, black and yellow berry trees	-	Beginning of the warm season	Jabik (2022)
Shirui lily	Lilium mackliniae	Asia	India	Tangkhul Naga community (Northeast India)	Blooming of this plant	Summer	Time for transplantation of paddy	Varah & Varah (2022)
Star grass	-	Africa	Uganda	Rwenzori region	Withering	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)
Strychnos pungens (Muhwahwa)	-	Africa	Zambia	Sesheke district	Tree bears more fruits than usual	September and October	High likelihood above-average rainfall with	Mushimbei & Libanda (2022)

							very short and infrequent dry spells	
Tarmeranda tree (Pusik)	-	Africa	Ghana	Northern region (Sabare community)	When the tree grows fresh leaves	-	Onset of rains	Ankrah, Kwapong & Boateng (2022)
Thola	Parastrephia lepidophylla	South America	Bolivia	Umala municipality	-	August 15 - October 15	Planting time and type of year (seasonal forecast)	Gilles et al. (2022)
Thola	Parastrephia lepidophylla	South America	Bolivia	Ancoraimes municipality	-	August 15 - October 15	Planting time and frost likelihood	Gilles et al. (2022)
Tree (Emire)	Terminalia ivorensis	Africa	Ghana	Western region (Sewfi Bosomoiso community)	Sprouting of new leaves	-	Start of the rains.	Ankrah, Kwapong & Boateng (2022)
Tree growth	-	Africa	Ethiopia	Burkitu watershed	New growth of tree species such as Commiphora erythraea (Agarsu), Lanne arivae (Handaraku) and Commiphora africana (Ammeessa) produces green leaves	April	Start of the major rainy season	Guye, Legesse & Mohammed (2022)

Trees	-	Africa	Zimbabwe	Limpopo Province	Motoma, marakarakane and Mothokolo, Motika and wild fig trees had many fruits	-	Above average rainfall coming rainy season	Andersson et al. (2020)
Trees	-	Africa	Uganda	Rwenzori region	Shade leaves; bring new shoots and leaves	-	Indicator for onset of rains (2.1%), cessation of rains (1.8%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Trees	-	Africa	Benin	Kandi, Glazoué & Zè commune	Phenology of trees is used in climate forecasting	-	-	Amegnaglo, Mensah-Bonsu & Anaman (2022)
Trees: "Githumura"/ Tamarind	-	Africa	Kenya	Kitui Central	Changes from green to reddish-brown	-	Wet conditions approaching, meaning that land preparations should start	Mugi-Ngenga et al. (2021)
Trees: Fig tree, Acacia, Baobab	Fig tree: Ficus sycomorus; Acacia: A. tortilis, A. mellifera, A.	Africa	Kenya	Tharaka South	Fig tree, Acacia and Baobab showing re-growth	-	Indicates onset of rains, meaning that land	Mugi-Ngenga et al. (2021)

	nilotica, A. ataxacanthia; Baobab: Adasonia digitate						preparation can start	
Tropical coral tree	Erythrina spp	Africa	Uganda	Rwenzori region	Flowering; shade leaves	-	Indicator for onset of rains (0.9%), cessation of rains (0.8%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Vernonia amygedaiina	Vernonia amygedaiina	Africa	Uganda	Rwenzori region	Flowering	-	Indicator for onset of rains (0.2%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Wild Himalayan cherry flowers (sahārwon)	-	Asia	India	Tangkhul Naga community (Northeast India)	Fresh leaves sprouting	Spring (*Mayo s*eason)	Time to sow seeds such as maize, pumpkin, cucumber, garden egg	Varah & Varah (2022)
Winter thorn	Faidherbia albida	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Sprouting of leaves of the winter thorn	-	Indication of the setting in of the dry season	Jabik (2022)
Yao yín	Lycium ameghinoi	South America	Argentina	Central-north region of Chubut	Small plants with a change in shape	-	Lack of fodder (long-term change)	Castillo, Rostagno & Ladio (2020)

X.A.6 – Other

Table A.X - 15 Rainfall indicators which do not fit in the other categories.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Prediction	Source
Animal intestines	-	Africa	Ethiopia	Burkitu watershed	If the amount of food available in the large intestine, small intestine, and lymph node is very small (nearly empty)	-	The worst season has begun (and vice versa)	Guye, Legesse & Mohammed (2022)
Animal intestines	-	Africa	Ethiopia	Burkitu watershed	If the intestine of a freshly slaughtered animal appears black	-	Good season or normal rainfall	Guye, Legesse & Mohammed (2022)
Animal intestines	-	Africa	Ethiopia	Burkitu watershed	Greyness, whiteness, or nearly reddish colour of the intestinal part under read	-	Severe weather events, most notably the onset of a long dry season	Guye, Legesse & Mohammed (2022)
Animal intestines	-	Africa	Ethiopia	Burkitu watershed	The length and thickness of gut organs. When the big intestine or lymph nodes	-	Signals start of a terrible season (and vice versa)	Guye, Legesse & Mohammed (2022)

					are too short or thin			
Animal intestines	-	Africa	Ethiopia	Burkitu watershed	Change in colour of blood vessels from red to brilliant yellow or grey	-	Rain will be arriving soon	Guye, Legesse & Mohammed (2022)
Animal intestines (sheep or goat)	-	Africa	Ethiopia	Gomole district	When darker spots are witnessed on the intestine swathe	-	Plentiful rain in the coming rainy season	Dejene & Yetebarek (2022)
Animal intestines (sheep or goat)	-	Africa	Ethiopia	Gomole district	When more blood spotted in the interior parts of intestine	-	Near rainfall inception and a virtuous rainfall season ahead	Dejene & Yetebarek (2022)
Animal intestines (sheep or goat)	-	Africa	Ethiopia	Gomole district	When the blood veins are unevenly seen on the exterior parts of the intestine	-	Trivial rainfall in the imminent rainy season	Dejene & Yetebarek (2022)
Animal intestines (sheep or goat)	-	Africa	Ethiopia	Gomole district	No blood seen in the vessel and intestine looks bright	-	Imminent drought	Dejene & Yetebarek (2022)
Asthma	-	Africa	Uganda	Rwenzori region	Asthma people have difficulty	-	Indicator for onset of rains (0.1%)	Nkuba et al. (2020)

					breathing at night			
Birth of boys (Kuzvarwa kwevakomana vakawanda)	-	Africa	Zimbabwe	Bikita district	Birth of many boys	-	Associated with drought (--> get prepared for coping with droughts)	Mafongoya, Mafongoya & Mudhara (2021)
Birth of girls (Kuzvarwa kwevasikana vazhinji)	-	Africa	Zimbabwe	Bikita district	Birth of many girls	-	Bumper harvests are expected, more intensive farming	Mafongoya, Mafongoya & Mudhara (2021)
Body temperature	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (1.5%), cessation of rains (0.1%), 5-day forecasts (5.6%)	Nkuba et al. (2020)
Children	-	Africa	Ethiopia (central)	Oromo community	Children unusually crying for food	-	The coming season will be bad	Mekonnen et al. (2021)
Earthquakes	-	Africa	Uganda	Rwenzori region	Surface earthquakes; from east to west (to Lake Albert); earthquakes during end of drought/dry season; female	-	Indicator for onset of rains (11l6%), 5-day forecasts (1.7%), seasonal forecasts (2.2%)	Nkuba et al. (2020)

					earthquakes take place; heavy shaking of earthquake			
Earthquakes	-	Africa	Uganda	Rwenzori region	From north to south; from west to east (from Lake Albert); earthquakes during the rainy season; underground earthquakes	-	Indicator for cessation of rains (9.3%)	Nkuba et al. (2020)
Feeling weak	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.2%)	Nkuba et al. (2020)
Festive days	-	Asia	Nepal	Kirtipur	Certain festive days	-	Days with rainfall	Poudel et al. (2022)
Hamattan	-	Africa	Nigeria	Delta state	Hamattan.	-	If the hamattan stays until March, it indicates that there will be less rainfall than usually observed for the forthcoming planting season. But, if it ends in	Ebhuoma (2020)

							January, there will be adequate rainfall in the forthcoming planting season.	
Headache	-	Africa	Uganda	Rwenzori region	Headache	-	Indicator for onset of rains (0.2%), 5-day forecasts (0.2%)	Nkuba et al. (2020)
Knees and back	-	Africa	Uganda	Rwenzori region	Pain in the knees and back	-	Indicator for onset of rains (0.2%)	Nkuba et al. (2020)
Lake	-	Africa	Uganda	Rwenzori region	Waves of water on Lake Edward	-	Indicator for onset of rains (0.3%), cessation of rains (0.1%), 5-day forecasts (0.1%)	Nkuba et al. (2020)
Lake	-	Africa	Uganda	Rwenzori region	Lake is settled	-	Indicator for cessation of rains (0.1%)	Nkuba et al. (2020)
Lake	-	Africa	Ethiopia (central)	Oromo community	Colour of lake becomes black	-	It will be a good season	Mekonnen et al. (2021)
Peace in the heart/holy feeling	-	Asia	Indonesia	Jawa	When the bioclimate induces a feeling of "piece in the heart". Arrival	-	Indicates shifting seasons, from dry to rainy	Zaki et al. (2020)

					of rainfall leads to a "holy feeling" associated with the green colour of plants			
Pests and diseases	-	Asia	Indonesia	Jawa	When pests and diseases are carried by the wind	-	Beginning of the rainy season	Zaki et al. (2020)
Rituals	-	Asia	Nepal	Thapuwa & Bikri (Gulariya municipality, Bardiya district)	The Tharu perform rituals called *gaiya berhna* and *magha lotna* to induce rain. The Tharu believe that the god of rain, Indra, listens to the voice of people in the performance of *gaiya berhna* and to children's rain requests in the form of producing the sound of a	-	-	Chaudhary et al. (2021)

					frog in *magha lotna*, as the Tharu believe that rain comes upon the crying of the frog			
River	-	Africa	Uganda	Rwenzori region	Ngusi and Muzinzi Rivers make sounds (responding to each other)	-	Indicator for onset of rains (1.3%)	Nkuba et al. (2020)
River	-	Africa	Uganda	Rwenzori region	No sounds from Ngusi and Muzinzi Rivers	-	Indicator for cessation of rains (0.2%)	Nkuba et al. (2020)
Sacred mountains (Makomo anoera)	-	Africa	Zimbabwe	Bikita district	Sounds from sacred mountains toward rainy season	-	Imminent rains (--> farmers should prepare their fields for cultivating)	Mafongoya, Mafongoya & Mudhara (2021)
Salt piles	-	North America	Mexico	Yucatán Peninsula	12 piles of salt divided in two lines of 6 piles are to be placed on a table outside the house during the last night of the year	-	There is going to be humidity in that month of the year	Camacho-Villa et al. (2021)

					(December 31st). Before *Xook K'iin* starts on January 1st, people check each pile and, if the pile disintegrates			
Seasonal calendar events	-	Africa	Uganda	Rwenzori region	-	-	Indicator for onset of rains (0.8%), cessation of rains (2.1%), 5-day forecasts (0.6), seasonal forecasts (1.1%)	Nkuba et al. (2020)
Soil	-	Asia	Indonesia	Jawa	When the soil becomes cracked	-	Beginning of the dry season	Zaki et al. (2020)
Soil (tankpari)	-	Africa	Ghana	Kumbungu district (Northern Ghana)	Dry soil with fresh, sweet, powerful smell	-	Rain the next day	Nyadzi et al. (2021)
Soil/dust	-	Africa	Ethiopia (eastern)	Somali community	When soil erosion by wind becomes prevalent with dust storms; poor pasture, drying of water points,	-	Sign of drought for the coming season	Mekonnen et al. (2021)

					soil compacted and crusted, the formation of sand sheets and dunes by frequent sand storm			
Sound	-	North America	Canada	Pond Inlet, Nunavut	When they hear snowmobiles from farther away than normal	-	It will become windy	Simonee et al. (2021)
Sweating	-	Africa	Uganda	Rwenzori region	Sweating at night	-	Indicator for onset of rains (0.3%)	Nkuba et al. (2020)
Water colour	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	If the water of rainfall appears whitish	-	1. Likelihood of drought is higher, 2. Crops such as millet have better chances of having higher yields in that year than other crops	Jabik (2022)
Water colour	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West	If the water of rainfall is black	-	Crops such as guinea corn are anticipated to	Jabik (2022)

				and Tempane districts)			have a good yield	
Water levels	-	Africa	Uganda	Rwenzori region	Water levels on lake (Albert) draw toward the lake	-	Indicator for seasonal forecasts (0.1%)	Nkuba et al. (2020)
Xook K'iin	-	North America	Mexico	Yucatán Peninsula	The Mayan Xook K'iin is a longstanding method use to predict climate variations and phenomena throughout the year. It is based on observations of sun intensity, cloud density, presence of fog, rain and low temperatures during each day of January. Observations are made usually during daylight hours.	-	-	Camacho-Villa et al. (2021)

X.B – Documentation of Local Soil Moisture Indicators

Table A.X - 16 Soil moisture indicators.

Indicator name	Scientific name	Continent	Country	Region	Indicator signal	Observation period	Status/prediction	Source
Alfilerrillo	Erodium cicutarium	South America	Argentina	Central-north region of Chubut	Large numbers in spring	-	Moist soil (short-term change)	Castillo, Rostagno & Ladio (2020)
Botón de oro	Grindelia chiloensis	South America	Argentina	Central-north region of Chubut	Presence of plant	-	Sandy soil	Castillo, Rostagno & Ladio (2020)
Calafate	Berberis microphylla	South America	Argentina	Central-north region of Chubut	Presence of plant	-	Moist soil	Castillo, Rostagno & Ladio (2020)
Cortadera	Cortaderia sp.	South America	Argentina	Central-north region of Chubut	Presence of the plant	-	Moist soil	Castillo, Rostagno & Ladio (2020)
Dawadawa tree (African Locust tree)	Parkia biglobosa	Africa	Ghana	Northern Ghana	Immediately when harvest of ripe fruits starts	Rainy season (May to June/July)	Suitable for any type of crop	Sutanto et al. (2022)
Earthworms	-	Africa	Ghana	Northern Ghana	Earthworms on the earth surface after it rained indicate effective rainfall	Rainy season	Soil is suitable for sowing since moisture is related to rainfall	Sutanto et al. (2022)
Fig tree (kinkang tree)	-	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West	Presence of the fig tree	-	Signifies the presence of a high underground	Jabik (2022)

				and Tempane districts)			water table around that area	
Gbingbane plant (at maturity stag)	-	Africa	Ghana	Northern Ghana	When poultry or small animals (cat) can hide behind shrub without being seen	Onset of the rainy season (April/May)	Soil ready for sowing/planti ng	Sutanto et al. (2022)
Karifi maalam plant	-	Africa	Ghana	Northern Ghana	1. When it starts to fruit, 2. When its fruits start ripening. From the start of ripening to fully ripe fruits.	Rainy season (May/June)	1. Good for sowing of groundnuts and maize, 2. Good for planting of rice	Sutanto et al. (2022)
Shea tree	Vitellaria paradoxa	Africa	Ghana	Northern Ghana	Immediately after the fruits start ripening	Onset of the rainy season (April/May)	Soil ready for sowing/planti ng	Sutanto et al. (2022)
Termites	Isoptera	Africa	Ghana	Upper East Region (Garu, Binduri, Bawku West and Tempane districts)	Presence of termites in an area	-	Underground water or the water table is high in the area	Jabik (2022)