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HYDRO-CLIMATE INFORMATION SERVICES IN GHANA: FARMER SUPPORT APPLICATION IMPLEMENTATION AND EVALUATION

BY

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DECLARATION

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I hereby declare that this dissertation/thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere:

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ABSTRACT

Agriculture in Africa depends more on rainfall than irrigation. In ancient days, older people in farming communities relied on their perceptions, instincts and observations of the surrounding biota (flora and fauna) to plan their agricultural activities. These ideas, experiences and knowledge of local people had gained attention in the discussions of climate change and adaptation strategies in Africa essentially relating to agricultural sustenance. Evidence from literature shows that in recent times forecast which is based on modern technology (scientific forecast) had received a lot of attention and has been adopted by many rural farmers in the developing world due to its precision. Several researchers had inferred that the way forward to adaptive and reliable weather forecasting is by integrating indigenous forecast with scientific forecast. This study was carried out in the Yapalsi and Nakpanzoo rice valleys to evaluate the benefits and drawbacks of the Farmer Support Application (FSApp) which is a tool developed through a participatory approach to address the climate information needs of farmers with regards to rainfed agriculture. This FSApp works by receiving scientific forecast from meteoblue and local forecast from the farmers and displaying both scientific and local forecast information to farmers for making informed decisions pertaining to agriculture. To achieve the aims of the research, standard rain gauges were installed in both communities to record rainfall data. The rice farmers in both valleys were then trained to use the FSApp for making daily decisions which involved the daily entry of forecast by farmers using indigenous ecological indicators. All the data entered into the FSApp were recorded as local forecast data and stored on servers. At the end of the season, the local forecast data was retrieved from the server, scientific forecast data was obtained from meteoblue and the predictive accuracy of the FSApp was assessed using the rain gauge data as the reference. The final evaluation was also carried out using focus group discussions and questionnaires to assess the outcome of the project on the farmer's agricultural livelihood. Results indicated that an integration of Scientific Forecast Knowledge (SFK) and Local Forecast Knowledge (LFK) amounted to the highest skill score of 0.62 followed by SFK with a score of 0.61 and LFK with a score of 0.50. These skill score values show a significant predictive skill of the various forecast scales (SFK, LFK and Integration of SFK and LFK). The best accuracy of predictions was observed when LFK was integrated with SFK relative to the sole skills of SFK and LFK even though a significant difference was not observed between the scores of SFK and the integrated score. It was also revealed that farmers relied more on celestial bodies (Sun and Moon) for local weather prediction such that, 85.9% of indicators used by farmers for predictions were observations of celestial bodies. Results revealed that co- production played a vital role in the adaption of the farmer support app. Farmers demonstrated a significant (high) level of knowledge about weather phenomena and knowledge sharing among farmers was observed to have increased. The farmer support app performed as expected and therefore recommended to other farming communities that rely on rainfed agriculture.

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DEDICATION

I dedicate this work to my beloved mother, Mrs. Happy Abla Afatsawu and my aunt, Mrs. Kate Afatsawu.

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LIST OF ACRONYMS AND ABBREVIATIONS

ALP - Adaptation Learning Programme

API – Application Programming Interface

CARE - Cooperative for Assistance and Relief Everywhere

CCAFS - Climate Change, Agriculture and Food Security

CICs - Climate Information Centres

CSIR - Council for Scientific and Industrial Research

EPA - Environmental Protection Agency

FAO – Food and Agriculture Organization

FAR – False Alarm Rate

FRI - FARM Radio International

FSApp – Farmer Support Application

GCA - Global Commission on Adaptation

GFDRR - Global Facility for Disaster Reduction and Recovery

GMet - Ghana Meteorological Agency

H-K - Hanssen-Kuipers discriminant or Pierce Skill Score

IF - Indigenous Forecast

IK - Indigenous Knowledge

IPCC Intergovernmental Panel on Climate Change

LFK – Local Forecast Knowledge

MDF – Management for Development Foundation

MDGs - Millennium Development Goals

MESTI - Ministry of Environment, Science, Technology and Innovation

MoFA - Ministry of Food and Agriculture

NADMO - National Disaster Management Organisation

NCCC - National Climate Change Committee

NDCs - Nationally Determined Contributions

NEMS - NOAA Environment Modeling System

NGO's – Non-Governmental Organisations

NMM - Non-Hydrostatic Mesoscale Models

NOAA - National Oceanic and Atmospheric Administration

ODI - Overseas Development Institute

POD - Probability of Detection

POFD - Probability of False Detection

RCOF - Regional Climate Outlook Forum

RCP Representative Concentration Pathway

SARUA - Southern African Regional Universities Association

SFK – Scientific Forecast Knowledge

SIDS - Small Island Developing States

SME's – Small and Medium Enterprises

UNESCO - United Nations Educational, Scientific and Cultural Organisation

UNFCCC - UNFCCC - United Nations Framework Convention on Climate Change

URL - Uniform Resource Locator

USAID - United States Agency for International Development

WACWISA - West African Centre for Water, Irrigation and Sustainable Agriculture

WBG - World Bank Group

WMO - World Meteorological Organization

WSG - Water Systems and Global Change group

CHAPTER ONE

INTRODUCTION

1.1 Background

Climate is one of the major determinants for success in the agricultural sector, rural livelihoods and sustenance. The interest in developing climate services for a variety of users has received significant attention over the last decade and a half, based on improved forecasting capabilities (Vaughan and Dessai, 2014). This growing interest in promoting climate services was to encourage mitigation of climate-related risk in agriculture, disaster risk reduction, adequate water management, health protection, support to the energy and a variety of other vulnerable sectors. (Tall *et al*., 2018).

Most African economies heavily depend on the agricultural sector for development and Ghana is not an exception. In Ghana, the majority of the farmers are engaged in rainfed small-scale farming (FAO, 2016). The success of rainfed agriculture depends on how best the farmers are able to march their decisions regarding farm practices to the prevailing weather. Accessibility of hydro-climatic information services is essential for sustainable agricultural practices and therefore increasing adaptation potential of farmers which will lead to better yields and minimum risk of crop failure. Farmer’s ability to make climate-smart decisions for optimum crop production will depend largely on the availability of accurate and timely climate information (Nyadzi *et al*., 2019).

Currently, farmers are not able to make sufficient use of the existing hydro-climatic information services provided mainly through governmental channels, private organisations, and NGO’s, due to how the information is generated and disseminated (Sultan *et al*., 2020). A research carried out by Gbangou *et al.* (2020), revealed that small-scale local farmers depend mainly on indigenous knowledge for farming decisions due to the lack of localised information and inadequate understanding of modern scientific forecasts. The involvement of local farmers in the creation of forecast knowledge can help promote trust and increase the uptake and understanding of scientific forecasting knowledge. Also, the collection and integration of indigenous or local knowledge with scientific data can help increase credibility and improve the acceptability of scientific forecast among local farmers (Nyadzi *et al.*, 2020; Gbangou *et al.*, 2020).

Climate services lack sufficient information due to the preferred use of traditional communication systems, the unreliability of service and lack of user's engagement in the development of the climate services. (Kumar *et al*., 2020; Gbangou *et al*., 2020; Chowdhury, 2005). The development of climate services for farmers has to be a full package where farmers will be involved from the beginning to the end, so that information provided to farmers can be credible, salient, attractive, trustable, and dependable in order to make informed decisions. (Hansen *et al*., 2011). According to Kumar *et al*. (2020), capacity building of farmers is very essential for the adequate use of hydro-climate information services since this increases the knowledge of farmers about hydro-climatic information.

Climate impacts are being felt already through the change in; average temperature, rainfall, moisture in the air, vegetation, and increases in the frequency of droughts. (Pelling, 2011). The agricultural sector is particularly suffering from the high occurrence and unpredictability of extreme climatic events. Agricultural systems highly rely on the climate. The notable trends of increasing frequency of weather-related events over the past decades pose a significant challenge to the performance of the agricultural sector. Disasters such as droughts and floods which are prevalent in most deprived agricultural communities can occur in isolation, or simultaneous combination, with significant effects. Emergencies of this nature pose serious challenges to agricultural production and food security. (Jentsch and Beierkuhnlein, 2008; FAO, 2018).

The unpredictability of weather conditions is a major concern for small-scale farmers in developing countries where agriculture is mostly rainfed (Gbangou *et al*., 2019; Cooper *et al*., 2008). In Ghana, the situation is worsened by the hot and dry climate (Mendelsohn *et al*., 2006), with consequent drought and occasional heavy torrential rainfall (Nyamekye *et al*., 2019).

The provision of timely and accurate climate predictions has the potential to reduce climate-related risks and uncertainty in farmers decision-making processes (Nyamekye *et al*., 2018). For this reason, the development of tailored and skilful weather and climate information based on local weather conditions is becoming important in order to increase the understanding of climate variability for farmers (Gbangou *et al*., 2019).

An attempt to help smallholder farmers in Ghana deal with this changing climatic situation had been carried out with the pilot implementation of the Farmer Support Apps (FSApps) in the year 2018 under the WATERAPPS research project (www.waterapps.net), with researchers from Ghana, Bangladesh and The Netherlands collaborating to meet their needs. The project aimed to develop tailor-made water information services in southern Ghana. This will improve water management on the field and increase food security while achieving knowledge co-creation and sharing within the farming community (Gbangou *et al*., 2020).

Development of the FSApp was carried out by the Water Systems and Global Change Group (WSG) in Wageningen University and Research in the Netherlands, in collaboration with researchers from the University for Development Studies in Ghana and Small and Medium Enterprises (SME's) as well as Management for Development Foundation (MDF) West Africa and SpaceWek. This application (Farmer Support App[1]) was designed to provide weather forecast to users by integrating scientific weather predictions with indigenous knowledge from

[1] https://play.google.com/store/apps/details?id=com.spacewek.farmersupport

the farmers. Therefore, a bottom-up approach was being used in the development and utilization of forecast information where Farmers were directly involved in the creation and sharing of climate information amongst the members of their community.

1.2 Problem Statement and Justification

With the increasing incidence of climate change, the provision of timely and accurate climate predictions has the potential to reduce climate-related risks and uncertainty in farmers' decision-making processes (Nyamekye *et al*., 2018). The Northern region of Ghana is fairly dry, with most of the rural population practising rainfed small-scale agriculture. Climate variability and change is very pronounced in this area of Ghana, making the communities vulnerable to frequent crop failures (Gbetibouo *et al*., 2017). For this region, tailored weather and climate information, based on local weather conditions is becoming very important in the understanding of climate variability (Gbangou *et al*., 2019).

However, the lack of efficient communicating channels for weather and climate information services and inadequate technology extension in agriculture has created barriers to the availability of scientific weather forecast information services for farmers. As a result, farmers have no other option but to solely depend on traditional methods of weather forecasting, which is no longer enough to make appropriate decisions due to the rapid changing of weather parameters (Codjoe *et al*., 2014). This has led to instances where farmers plant too early following a "false" onset of the growing season, which often leads to crop failure and the need for expensive replanting (Roncoli *et al*., 2002; Wetterhall *et al*., 2015; Dunning *et al*., 2016). Inadequate forecast information could also result to late harvesting which leads to massive post-harvest losses among rice farmers.

Also, there are barriers to climate information uptake and use derived from how knowledge is conceptualised and presented. A major constraint is that little attention is given to the context in which people live and operate, therefore the co-creation of knowledge is missing (Jasanoff, 2010). Vogel *et al*. (2019) argue the need for a more in-depth understanding of how the knowledge is created and shared in the entire African continent, calling for the inclusion of users in the whole process.

The study aimed to assess the developed climate information services with and for farmers by evaluating a newly developed FSApp within the scope of the FSApps project. The FSApp incorporates scientific and integrated forecast through an easy visualization scheme. The users have the opportunity to add their local forecast and observations in the APP which is incorporated and depicted alongside the scientific forecast.

1.3 Objectives of the Study

1.3.1 General Objectives

The General objective of this study is to assess the FSApp principles, its field implementation to test its proof-of-concept and to evaluate its use among the experimental communities in northern Ghana.

1.3.2 Specific Objectives

I. To build the capacity of farmers to enable them to use the FSApp.

II. To assess the accuracy of the FSApp predictions in relation to the ground truth.

III. To evaluate the impact of the FSApp with regards to low land rice farming in selected communities.

1.4 Research Gap and Questions

To achieve the mentioned objectives, the following main research question was considered:

What are the perceived benefits of the FSApp for low-land rice farmers in Yapalsi and Nakpanzoo communities in the Savelugu district of Ghana?

To address the main research question, the following sub-questions will be addressed:

i. What are the steps to build the farmers' capacity through the FSApp?
ii. What are the skills of the FSApp in terms of accuracy in predicting the weather in relation to the ground truth?
iii. What are the outcomes of the implementation of the FSApp on farmer's agricultural practices?

1.5 Structure of the Thesis

This thesis is structured into five main chapters: Chapter One (1) Presents an introduction to the study which elaborates on the following; background to the study, problem statement and justification, objectives of the study and research questions. Chapter Two (2) presents a literature review on the relevant topics relating to climate services and models. Chapter Three (3) outlines the materials and methods used in the study; description of study areas, description of the materials used for the study, methodology for data collection and analysis and comparative performance assessment indicators used in the study. Chapter four (4) presents the results and discussions and the final Chapter (chapter five (5)) presents the conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Climate Change Impacts and Severity

Currently, 20-80% of the global annual variation in the yield of crops is associated with weather phenomena and 5-10% of national losses in agricultural production are analogous with climate variability (FAO, 2019). In developing countries, agriculture suffers the most from weather variability and accounts for up to 26% of the damage resulting from climate variability and loss during climate-related disasters. Additionally, the global demand for food will increase by 50% and in the absence of prompt climate action, yields may decline by up to 30% by 2050 (GCA, 2019). Climate change has potentially dire effects on the environment, society, and economy as a whole. Changes in the average temperature lead to changes in other climatic parameters affecting rainfall patterns amongst others resulting in floods, droughts, intense rain and frequent and severe heat waves. The agricultural sector suffers most from the impacts of these extreme climate events (IPCC, 2017).

2.2 Vulnerability to Climate Change

Climate change is happening globally but its impacts are not equally shared across regions. The most affected victims of extreme climate events are nationals of developing countries (Solomon *et al*., 2007; IPCC, 2013; World Bank, 2013). According to the Global Climate Index 2016, developing countries are generally more susceptible to the impacts of climate change than developed countries (Kreft *et al*., 2016). These changes often create problems for small scale farmers and other vulnerable land-users in securing their livelihoods. (Gbetibouo *et al.*, 2017).

Furthermore, these countries' economies depend largely on agriculture, which is sensitive to climate variability (Gbangou *et al*., 2019; WMO, 2019). Particularly, developing countries generally have a lower adaptive capacity to the adverse impacts of a changing climate relative to the developed world. It is anticipated that developing countries lack adequate human and financial resources, and adequate access to technology to help with adaptation (Harry and Morad, 2013). Smallholder farmers in developing countries are considered to be one of the most vulnerable groups to climate change impacts, particularly droughts (Ozor and Nnaji, 2011; Akinnagbe and Irohibe, 2014) since their livelihoods are directly dependant on agriculture (Truelove *et al*., 2015; Lewis and Impiglia, 2018).

Climate change will exacerbate existing vulnerabilities and will reduce the ability of smallholder farmers to access water, produce crops and earn income. Furthermore, regional weather patterns such as the monsoon rains are also projected to reduce by 70% in the late 21st and early 22nd centuries, (Loo *et al*., 2015). Some areas will be flooded while others will face droughts, resulting in challenges with crop production. Millions of farmers will be forced to migrate temporarily or even permanently, and pushed into hunger. Alongside this and ocean acidification, as well as the world population increase, human beings will also experience shortages of water for consumption and use. Rice production in particular will be reduced since rice is a high water-consuming crop. The International Rice Research Institute stated that for every 1^0C increase in the minimum temperature at night in the dry season rice yields will reduce by 10% (Mohanty *et al*. (2013).

2.3 Adaption to Climate Change

The need for adaptation to climate change is recognized as pressing and necessary (Nyantakyi-Frimpong and Bezner-Kerr, 2015). The numerous strategies employed towards livelihood adaptation to climate change and variability, operate under several unknown conditions. Such unknown conditions, according to Watson *et al*. (2016) are as follows; it’s not precisely known, what the impact of climate and ecological change at the local level is or will be, or how other aspects of the environment associated with it will be impacted across multiple scales. These complications and uncertainties call for localized case studies to better analyse the situation through their assessment of life experiences of resource-poor small-scale farmers and communities in developing countries in surviving and adapting to climate change and variability (Berrang-Ford *et al*., 2015).

Adaptation strategies refer to the medium to long-term adjustments of human beings to a changing climate at present, or to an expected future climate. In human systems, adaptation also aims at moderating the harm resulting from climate variability (IPCC, 2014). International and national climate change policies have increasingly focused on adaptation measures during the last decade (Harmer and Rahman, 2014) to maintain the possibility of sustainable development and poverty reduction (Harmeling, 2010) because mitigation policies were not successful (Khan and Roberts, 2013). Adaptation equally refers to the decision-making process and the set of actions performed to maintain the capacity to deal with current or future predicted change (Nelson *et al*., 2007). According to Aniah *et al.* (2019), adaptation is a multi-faceted decision-making process. It is a function of an individual or situational (climate change risks) circumstances of the subject to the decision and the characteristics of the innovation under consideration which occurs within a situation of changing economic, political, social and biophysical conditions (Rogers, 1995; Smith and Skinner, 2002). Coping strategies on the other hand refers to short-term measures used by households to reduce the adverse effects of climate variability on their livelihoods and well-being over a short period normally less than a calendar year (Engle, 2011).

Human beings have been adapting to climate change for a long time, but due to the virulent impacts of climate-related events, additional adaptation strategies will be needed to limit the adverse effects of projected global warming and variability, irrespective of mitigation efforts (IPCC, 2007). Adaptations are required for many less-developed countries to secure their livelihoods and food security (Connolly-Boutin and Smit, 2015; Knox *et al*., 2012). Since they have low adaptive capacities and are highly vulnerable to climate change impacts, even under moderate global warming, adaptation is needed to lessen their vulnerabilities which are projected to get worse if no action is taken (FAO, 2012; Truelove *et al*., 2015).

Different countries and different groups within countries have their ways and resources to cope with the adverse impacts of climate change. Wealthier and better-resourced countries have more opportunities to create changes whereas less-resourced countries need to invent unique ways to combat the negative effects of climate change. Climate change is starting to be factored into a variety of development plans. Effective solutions to address climate change require strong policy implementation and efforts from both individuals and government at all levels. At an international level, a wide range of adaptation funding systems, such as the Least Developed Countries Fund and the Adaptation Fund, have been developed under the UNFCCC and the Kyoto Protocol to reduce the adverse impacts of the changing climate (ODI, 2014; UNFCCC, 2012). These mechanisms were formulated to provide financial support to developing countries to adapt to climate change impacts by promoting adaptation strategies in development plans and actions (UNFCCC, 2012). At the national level, many governments have established adaptation plans and policies and considered integrating climate change issues into broader development plans (IPCC, 2014). The decision to implement adaptation measures (adopt innovations) depends more often on the availability and accessibility of adequate information, institutional support, education and strength of vulnerable households to survive (Bawakyillenuo *et al*., 2016).

2.4 Climate Services for Agriculture; a Foundation for Better Decision Making

The ability of farmers to make informed decisions through climate information provided by climate services leads to the generation of more value. Global estimates indicate that improved forecasting, weather, climate and water observations could amount to up to 30 billion USD per annum in increased productivity and up to 2 billion USD per year in reduced asset losses (Hallegatte, 2012). This trend of improved productivity and reduced losses could be crucial to lifting the millions around the world whose livelihoods are at risk of climate uncertainties out of poverty. The realization of these benefits and their contribution to sustainable development, global prosperity and poverty reduction is encouraging the development community to put in more capital in modernizing hydrometeorological services. (Rogers *et al*., 2013; WMO, WBG, GFDRR, USAID, 2015; GCA, 2019).

Currently, some African countries have recognized the value of climate services to supporting adaptation to climate variability. As of 2019, a significant majority of the parties referred to the importance of climate services in their Nationally Determined Contributions (NDCs), with Africa citing climate services most frequently (96%), relative to countries in Asia (83%) and South America (82%). Furthermore, all South-West Pacific countries that emphasized on agriculture and food security as a top priority in their NDCs also voted climate services as a means for achieving adaptation to climate variability, followed by Africa (94%) and Asia (91%). In particular, specified data, weather forecasting and observing networks as the top priority climate services-related needs to be addressed for developing countries.

Climate variability is a key concern for achieving food security in West African countries. Small scale farmers in developing countries depend largely on rainfed agriculture, implying that a deep understanding of climate variability is required to facilitate mitigation interventions such as the provision of climate information through climate services. According to Sylla *et al*. (2016), literature reveals that rainfall variability will increase as climate change advances. As a result of this variability, many small-scale farmers are facing challenges with regard to crop production since the rains are the only source of water for their plants (Cooper *et al*., 2008).

The provision of climate services for better adaptation outcomes depends on a simple, but comprehensive value chain. This value chain does not comprise only the production and dissemination of climate services, but also the impact on stakeholders, and involves the routine assessment of associated socio-economic costs and benefits (WMO, WBG, GFDRR, USAID, 2015). The agriculture sector is affected by climate variability in several ways, right from farm-level production to processing, shipping and marketing of agricultural produce. This document emphasizes services to farmers, who are the most vulnerable group in the Agricultural sector to be affected by climate variability (WMO, 2019).

The successful provision of climate services with proven demonstrated benefits needs to be operationalized globally (WMO, 2019). Evidence has shown that the benefits that will be accomplished by investing in the global-regional-national hydro-meteorological system outweigh the costs by about 80 to one. (Kull *et al*., 2016). National and international databases serve as sources to make climate information available and accessible to help individuals and organizations make climate-smart decisions. Climate information provided, such as; high-quality data on rainfall, soil moisture, temperature, wind and ocean conditions, as well as maps, risk and vulnerability assessments, analyses, and long-term projections and scenarios. These climate services provide decision makers in climate-sensitive sectors with better information to help society adapt to climate variability and change (WMO, 2019). Small scale rainfed farming is the dominant form of agriculture practised in most developing countries (FAO, 2016). Farmer's ability to make climate-smart decisions for optimum crop production will depend to a large extent on the availability of accurate and timely climate information.

Generally, the main agenda of most climate service providers is to provide a variety of interventions to aid individuals and organisations to build resilience by providing bottom line localised knowledge on the weather and climate. These services also aim to inform farmers and institutional decision-making about future changes, as well as creating an enabling setting for adopting new practises such as climate-smart agriculture (Dinku *et al*., 2017;). The development of climate services for agriculture can be traced back to the dual ambition of matching seasonal climate forecasting to agricultural systems and including agriculture in the development of seasonal climate predictions. In Africa, interest in developing climate services for a variety of users especially farmers have grown rapidly based on improved forecasting capability since the 1997/98 El Nino. (Vaughan and Dessai, 2014; Tall *et al.,* 2018). Within the same period, the Regional Climate Outlook Forums (RCOF) was also launched. Climate services in most countries within the continent are connected to the RCOF. (WMO, 2016; Hansen *et al*., 2019; WMO, 2020). Since their inception, RCOFs have been a focal point of international efforts to make seasonal climate forecasts information available across the developing world (Buizer *et al*., 2016; WMO, 2016). Several frameworks and programs have been proposed for climate services to provide timely, localized information and knowledge to a variety of users especially farmers to adapt and increase resilience towards climate variability (Vaughan and Dessai, 2014; Lourenço *et al*., 2016).

In Ghana, most climate scientists focus on producing and evaluating the quality of weather and climate information rather than understanding the use of the information created, leading to limited progress in building resilience towards climate variability. (McNie, 2013). As demand increases for climate services in the agriculture sector of Ghana, a number of challenges emerged which complicated the generation, dissemination, and use of forecast information for decision making. The mentioned challenges are not unique for Ghana but can be found in most parts of the developing world and in particular, sub-Saharan Africa (Vaughan *et al*., 2019).

2.5 Climate Services for Agriculture in Ghana

A major drawback to increasing agricultural productivity in developing countries is climate change. It is therefore essential to find possible ways of adapting agriculture to climate change. However, climate services are given less attention despite its role in agricultural productivity in Sub-Saharan Africa where the majority of the farmers do rainfed agriculture. (Naab *et al*., 2019). Several public and private organizations including local and international Non-Governmental Organizations (NGOs) are working to make climate services available to farmers.

The main national provider of climate information in Ghana is the Ghana Meteorological Agency (GMet). The GMet works in collaboration with several other organisations to aid information dissemination and utilization. Examples of such organizations are the National Disaster Management Organisation (NADMO), The Ministry of Food and Agriculture (MoFA), the Ministry of Environment, Science, Technology and Innovation (MESTI), Environmental Protection Agency (EPA), the National Climate Change Committee (NCCC), the Council for Scientific and Industrial Research (CSIR) and other local actors, with strong participation by the media. Several private organisations have recently emerged to provide climate services to small scale farmers in Ghana. (Naab *et al*., 2019) argued that forecast information provided by GMet has not been sufficiently useful for farmers. This is so because GMet was only responsible for producing climatic and weather forecast information, downscaling the information to meet the needs of the community and distributing to stakeholders including farmers. This disseminated weather forecasts information's were a general guide and often too technical for users to interpret, particularly small-scale farmers in rural communities. Therefore, climate services for agriculture in Ghana encounter several challenges. Due to this, several private sector providers, such as ESOKO have emerged providing tailor-made forecast information to farmers.

ESOKO started providing its services in 2008 and since then has been assisting enterprises to manage rural communities. Basically, ESOKO is focused on providing services to farmers, but the platform currently provides services to other enterprises as well. The aim was to see how the emergence of mobile technology in Africa could improve the livelihoods of rural communities across the continent. ESOKO has an objective to link farmers to organisations or enterprises and provide them with services such as weather forecasts, market linkages, agronomic advice and insurance coverage over a range of mobile channels including SMS, voice SMS and call centres. ESOKO Various research had seen such services being capable of improving farmers' incomes by roughly 10%.

Over time ESOKO has developed digital tools and services to help not only farmers but also extended their services to help agribusinesses and development organizations reach rural communities with services and productive solutions that help improve their livelihoods. Today, ESOKO connects over one (1) million farmers to essential services. Additionally, ESOKO has worked hard to make sure that farmers achieve maximum benefit from the services that they receive, by improving upon the mode and form of information services delivered to farmers through the development of apps to translate services provided in English into the local language of farmers (ESOKO, 2019).

Other efforts that have been made to advance climate services is the establishment of Climate Information Centres (CICs). Since the year 2012, Climate CICs have been established through a joint initiative between the CARE International Adaptation Learning Programme (ALP) and FARM Radio International (FRI, 2014). The purpose of the CICs is to use the development of radio broadcasting in rural areas of Ghana that are hard-to-reach so as to provide small scale farmers with an array of climate information relevant to agricultural practices. Information on best farming practices, weather forecast and tips on the appropriate period for cultivation is broadcast to farmers, helping them reduce the vulnerability of their agricultural activities to adverse climatic conditions (FRI, 2014).

Through collaboration between FARM Radio International, ALP, Ghana Meteorological Agency (GMET), and local FM radio stations, CICs have been successfully established in certain communities in northeast Ghana including; the Tariganga community of the Garu-

Tempane District and the Saamini community of the East Mampurusi District. CICs aim for both men and women to have equal access to information on climate forecasts, agricultural extension services, agro-meteorological advisories from PSP workshops, and a range of market information to inform decisions about their livelihood activities. CICs are designed to be managed by the communities, with technical support and advice from GMET and Farm Radio International. The CICs are been run by volunteers in the various communities by amplifying radio broadcasts with the help of loudspeakers to enable information broadcasts to reach wide community audiences. In addition, CICs link broadcasts to mobile phones for call-in programmes as well as general weather information distribution from GMET and other services such as ESOKO. (Gbetibouo *et al.*, 2017).

2.6 Challenges of Climate Services

Forecasts are a source of valuable information for decision making by small scale farmers in rural communities. Limitations on the utilization of climate information among local farmers, as reported by Climate Change, Agriculture and Food Security (CCAFS), include lack of information about the underlying local climate, forecast categories that may not provide information about thresholds needed for specific decisions and that are prone to misinterpretation, ambiguity about forecast accuracy and uncertainty, and sometimes lack of decision-relevant information beyond seasonal average rainfall (Hansen *et al*., 2019). Agriculture in Ghana, like in many other countries in sub-Saharan Africa, is being faced with similar climate related hazards, such as drought and flood. Yet current early warning systems are limited in their operations due to inadequate institutional data collection, storage and sharing problems (NADMO, 2015).

Currently, the technology for producing and disseminating climate information is being improved, yet studies reveal that climate information provided does not necessarily meet the specific needs of the end-users, particularly small-scale farmers (Onyango *et al*., 2014; Feleke, 2015). The limited access of smallholder farmers to localised climate information services makes them vulnerable to climate variability and poses a great threat to agricultural productivity and hence, their livelihoods. According to World Meteorological Organization (WMO) (2019), four challenging areas of climate services were identified to enhance climate services for effective adaptation in agriculture:

(i) Africa and Small Island Developing States (SIDS) are facing the largest capacity gaps in generating climate information. In particular, both regions are experiencing increasing difficulties with regards to the coverage of the observing network and reporting frequency of observations crucial for generating products and data needed by the sector. This makes it difficult to properly generate climate data and evaluate forecast quality in order to improve the forecast. In Ghana, for example, sparse weather stations provide limited coverage of areas necessary for rigorous spatial analysis

(ii) Globally, monitoring and evaluation of societal outcomes and benefits of science-based climate services for adaptation action stand out as one of the most challenged areas in the climate services value chain.

(iii) Coordination in the delivery and dissemination of climate services for the agriculture sector both within and across local, national, regional and international institutions and operational systems remains challenging. Lack of data sharing is resulting in sub-optimal availability and use of climate information and services. Inadequate communication of forecast uncertainties affects usage and uptake of climate services.

(iv) Although investments have increased significantly over the past decade, both more and better investments are required to ensure the provision of high-quality climate information services for adaptation action in agriculture. Better investments include investments that support the national-regional-global integrated hydro-meteorological system on which all countries depend in a more holistic, less piecemeal manner as well as investments in overcoming the "last mile" barriers impeding the full use and benefit of climate information and services.

In addition to the above challenges, the WMO has listed some more challenges that limit the generation and the dissemination of climate information at the required quantity, quality and timeliness. These include existing data policies that inhibit free and open data dissemination; unavailability of digitised climate archives that includes all climate elements; improper data generation and quality checks; existing gaps in climate observations due to malfunctioning of meteorological stations and lack of capacity in using satellite data services (WMO, 2006). These challenges are also seen to be affecting climate services for agriculture in Ghana (Nkrumah *et al*., 2014; Asante and Amuakwa-Mensah, 2015; Naab *et al*., 2019).

2.7 Scientific Forecast Knowledge (meteoblue)

Scientific weather forecasting is the application of science and technology to predict the conditions of the atmosphere spatio-temporarily. People have attempted to predict the weather informally for millennia and only started to do predictions formally since the 19th century. Weather forecasts are made by collecting quantitative historical data about the spatio-temporal state of the atmosphere using meteorology to project how the atmosphere will change. Weather forecasting in the present day relies on computer-based models that take many atmospheric factors into account (Dirmeyer *et al.*, 2009). Aside all the computer models and state of the art technologies used in the meteorological sector, human inputs are still required to pick the best possible forecast model to base the forecast upon, which involves teleconnections, pattern recognition skills, knowledge of model performance, and knowledge of model biases. Aside the massive development in the meteorological sector, forecast inaccuracy is persisting due to the following; chaotic nature of the atmosphere, the massive computational power required to solve the equations that describe the atmosphere, the error involved in measuring the initial conditions, and an incomplete understanding of atmospheric processes. Hence, forecasts become less accurate as predictions are being made more into the future.

2.7.1 meteoblue Ghana and the meteoblue API

The Application Programming Interface (API) is the means through which meteoblue shares forecast across the world. meteoblue provides high precision weather data for every place on land and sea, localised through point R technology. The meteoblue API is an URL-API that allows on-demand access to meteoblue weather data. Customers can query weather data in multiple formats or ready-to-use visualisations. The API handles queries almost instantaneously and can be integrated into automated systems, websites or applications easily. The FSApp which is a tailor-made app developed to support farmer's decision making processes was developed to combine both scientific and local predictions drawing forecast a step closer to accuracy in solving the problems of the small holder farmers, rely on the meteoblue API for its scientific forecast information section. The meteoblue weather provider provides localized weather data in hourly resolutions and additionally includes detailed information on topography, ground and surface cover aspects (Paparrizos *et al*., 2020; Cardinali *et al*., 2019).

2.8 Local Forecast Knowledge

'Indigenous' is synonymous with native or local where as "forecasting" in its simplest form is to predict (a future condition or occurrence). Generally, Indigenous knowledge refers to the skills, understandings and philosophies developed by communities with long histories of interaction with their natural surroundings. For rural and indigenous peoples, indigenous knowledge informs decision-making about rudimentary aspects of their daily life's. (Dunn, 2013). Indigenous knowledge is relatively cheap, readily available to rural people and an environmentally smart tool for sustainable development and adapting to climate variability

(Abeysinghe, 2013; Nchu *et al*., 2019). Environmentally-related problems, such as climate variability vary spatio-temporarily, but rural farmers have developed a vast knowledge about nature in their locale through continued experimentation, trial and error, and sustained interactions with their local environment, which has aided them in coping with and solving their problems (Boansi, 2017). The United Nations Educational, Scientific and Cultural Organisation (UNESCO) has a well-established program on preserving indigenous/ traditional knowledge, called Local and Indigenous Knowledge Systems, LINKS. This program was one of the key pillars that contributed to the framing of the Millennium Development Goals (MDGs) of poverty eradication and of environmental sustainability. (UNESCO, 2015; Tume *et al*., 2019).

Some efforts have been made to look into indigenous people's techniques for forecasting the weather and seasonal climate, but little is known about the skills of their techniques in accurately predicting the weather and seasonal climate (Gbangou *et al.,* 2019). Climate services provided to farmers are mostly of scientific origin and often too generalized, relative to being localised in order to provide specific information patterning to farmers own locality. For climate information to be usable, all stakeholders must be involved in its production, interpretation and dissemination (Lemos and Morehouse, 2005; Naab *et al*., 2019). Information provided is very important for farmers in making climate-sensitive decisions, concerning their farming activities. The joint production and dissemination of climate information offers an important mechanism of farmers' adaptation to climate change and ensuring resistance among smallholder farmers.

2.8.1 Weather Forecasting Using Local Knowledge and Associated Challenges

Small-scale farmers living in the rural communities of Ghana and other countries in Sub-Saharan Africa depend on indigenous knowledge, indigenous ecological indicators and traditional procedures and strategies as a means of forecasting the weather and climate.

(Antwi-Agyei *et al*., 2012; Tume *et al*., 2019) Some of the indigenous rainfall parameters and indicators used in the rural areas for weather and climate predictions include the following; the appearance of certain kinds of birds, chirping of particular birds, fruiting of particular trees at a specific period of the season, the germination of some plants, changes in cloud cover and wind pattern. The calling and ceasing of rains are also a traditional art undertaken by specific people in these rural communities called rainmakers.

However, in recent times, human activities such as forest-cover removal resulting in habitat destruction, loss in ecological equilibrium and climate variability, resulting in increasingly erratic weather conditions are making it difficult to rely on such indigenous knowledge and practices. Climate uncertainty often increases the risk of small-scale farmers since they depend solely on the rains to supply the required amount of water for their crops. This puts farmers in a very tight position pertaining to decision making in areas such as Land preparation, Sowing/transplanting, Fertilizer application, Pest control and harvesting.

The most realistic strategy to mitigate climate variability is using adaptations since weather and climate variability is beyond human control. Also, farmers have developed skills in understanding their environment and the changes associated with it over time. These skills are internally used in predicting the climate and weather pertaining mostly to rainfall. The ability to forecast the weather and climate accurately and timely will help farmers to adapt farm decisions to climate change. (Banerjee *et al*., 2003).

People around the world and most especially in Africa are able to understand their natural environment, through observations of their natural surroundings, combined with experience and historical knowledge to develop trends and skills that can be depended on for decision making referred to as Indigenous Knowledge (IK) (Orlove *et al*., 2010; Olsson *et al*., 2004; Gray and Morant, 2003). The applicability of IK has been studied and verified across the globe

(Cabrera *et al*., 2006; Desbiez *et al*., 2004). Across the globe farmers still use indigenous forecast (IF) today to adapt their farm practices to respond to local climate variability (Eriksen, 2005). The diverse forms of knowledge of these farmers, anchored in their relationships with the environment as well as in cultural cohesion, have allowed many rural communities to maintain a sustainable use and management of natural resources, to protect their environment and to enhance their resilience; their ability to critically observe their environment, adapt and mitigate has aided many indigenous communities to withstand new and complex circumstances that have often severely impacted their way of living and their territories. (Magni, 2016).

2.9 The Need for an Integration between Scientific Forecast Knowledge (SFK) and Local Forecast Knowledge (LFK)

Advancements in science and technology in recent times make it possible to provide short and long-term climate information services to support the farmers' decision-making processes. Several studies and surveys have shown that rural small-scale farmers use a combination of meteorological information referred to here as scientific forecast and indigenous IK in their weather and seasonal climate forecasting decisions (Tume *et al*., 2019; Roudier *et al*., 2014; Orlove *et al*., 2010). Although farmers use IK for forecasting weather and seasonal climate patterns, they are the first to also recognize the limitations in terms of accuracy, timing, and reliability (Naess, 2012; Roncoli *et al*., 2002). Studies have also shown that IK can serve as a basis for developing adaptation and natural resource management strategies and for understanding the potential for certain cost-effective, participatory and sustainable adaptation strategies (McLean and Nakashima, 2018; Naess, 2012). Relatively, not many studies have been done to systematically investigate indigenous ecological knowledge used by rural farmers for weather and seasonal climate forecasting. Even though some studies were carried out, the methodology that was used was largely qualitative which was limited in looking into the underlying mechanism (techniques) for IF and particularly quantitative test skills in these forecasts. It therefore became necessary to investigate and verify how accurate the indigenous forecasts of farmers are and the mechanisms underlying farmers' forecasting techniques for the chance of a possible integration. (Manyanhaire and Chitura, 2015).

2.10 Capacity Building

Agriculture is generally weather dependent, aside irrigated production. Yet, currently, farmers do not have access to reliable localized meteorological and agricultural information by which to plan and manage their farming operations. Information presently available is based on inputs from meteorological stations which are mostly located far away from most remote areas (villages). Local agro-meteorological conditions, especially rainfall, vary widely in space and such distantly located meteorological stations are not able to provide data that can generate locally relevant knowledge and advice (FAO, 2019). Also, the accurate interpretation and communication of information that meets the needs of farmers still remains a challenge till today as such, new approaches and methods are subsequently required to manage climate uncertainties at the local level. Additionally, providing tailor-made climate information at the local level can help increase the resilience of local people towards climate variability and give them a better chance of sustaining their livelihoods. (FAO, 2019; Kumar *et al*., 2020).

Local people plan their agricultural activities based on their experiences and their observations in the surrounding flora and fauna, which are gradually getting lost. Technology is also advancing at a rate that leaves local people behind, making them vulnerable. The most sustainable solution to this situation is for farmers to be aware of the changes in their environment and be given the capacity to understand, generate and utilize weather information. hence, it is important to retrieve, document, analyse, utilize and disseminate practices that are promising and useful by providing training to farmers to better understand weather-related phenomena and be willing and capable to operate, generate and interpret weather phenomena in their locality by themselves for making agricultural decisions and improving upon their adaptive capacity (FAO, 2019). This made capacity building a very crucial aspect of this project, where farmers were organised into climate groups and taught how to read climate forecasts together with their indigenous knowledge on climatic phenomena in relation to agriculture.

A typical example can be seen in FAO, 2019 where Climate Field Schools (CFS) were piloted by a project to disseminate knowledge about climate change, its causes, potential impact on livelihoods and local coping strategies. The climate field schools were seen as an innovative way to address problems on climate extremes, essentially through capacity building of farmers, with curricula adapted to address local conditions such as specific climate change-related knowledge and skills.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

This research was conducted in two (2) communities, namely; Nakpanzoo and Yapalsi in the Savelugu district of the Northern Region of Ghana. The Savelugu District is located in the Northern part of the Northern Region of Ghana. Geographically, the district is located between latitudes 9° 37′ 0″ North and longitudes 0° 50′ 0 ″ West and an elevation of 159.4 m as shown in Fig. 3.1.

Table 3.1: Geographical Coordinates of the Communities

Communities	Latitude (Decimal Degrees) N°	Longitude (Decimal Degrees) W°
Yapalsi	9.75487	-0.81826
Nakpanzoo	9.73892	-0.78038

(Source: Field survey, 2020)

The Northern region of Ghana is in a tropical Savannah zone which is characterized by a single rainfall season. It experiences a total annual rainfall of less than 1,100 mm. The agricultural potential of this region is reduced by high rainfall variability and poor soils. (Nutsukpo *et al*., 2012; Alhassan *et al*., 2013; Ghana.nl, 2018). The region experiences five (5) months of the rainy season in a year from May to October and a six months dry season that ranges from November to April (Amikuzuno and Donkoh, 2012). The unimodal rainfall and other harsh climatic parameters negatively affect agricultural production in this area. Projections from Owusu and Waylen (2009), states that the area will experience a decrease in rainfall frequency, increase in daily temperatures, and increase in rainfall intensity by the year 2050. Due to this, crop productivity is projected to decrease, which may put food security in this region at risk.

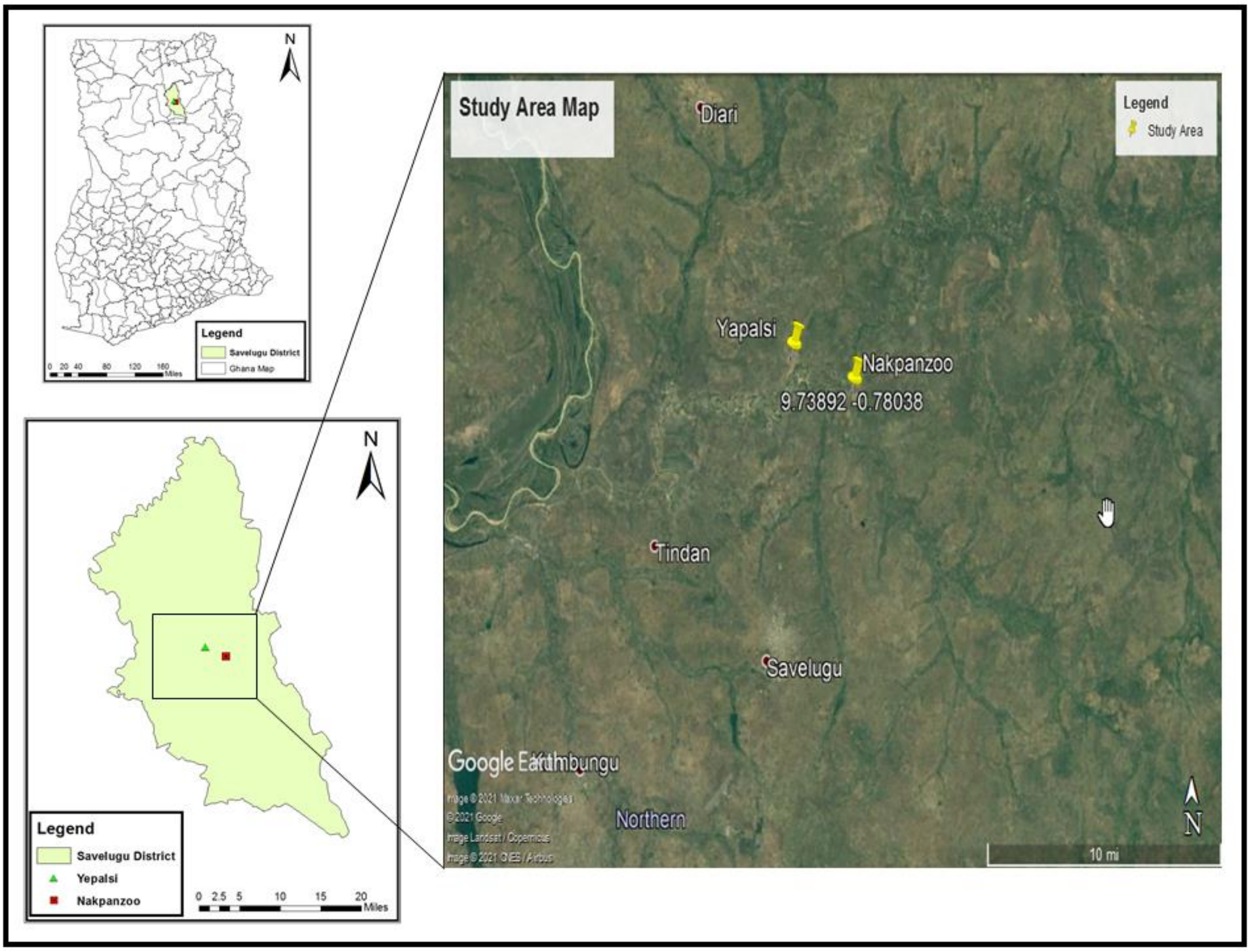


Figure 3.1: Study Area Map

(Source: Dogbey, 2020)

3.1.1 Climatic and Vegetative Characteristics of the Savelugu District

Climate

The Savelugu district falls within the Guinea savannah agro-ecological zone. The district is characterized by high temperatures with an average of 34^{o}C. The maximum temperature could rise to 42^{o}C and the minimum is as low as 16^{o}C during the harmattan period in the dry season.

Vegetation

The trees found in the area are drought resistant and hardly shed their leaves completely during the long dry season. Most of these are of economic value and serve as important means of livelihood, especially for women. Notable among these are Shea trees; *Vitellaria paradoxa* (the nuts which are used for making sheabutter) and "Dawadawa" (*Parkia biglobosa*) that provides seeds used for condimental purposes (Ansah and Nagbila, 2011; Wood, 2013).

3.1.2 Rice Cultivation in the Yapalsi and Nakpanzoo Communities in Savelugu District

The production of local rice in Northern Ghana has contributed much to the achievement of food security in the country. Rice is produced in smaller land holdings in the Savelugu District. In this district, rice production is just second to yam production in terms of quantity. According to a survey carried out in the year 2013 with a sample size of 14 farmers, it was revealed that the average acreage of land cultivated per farmer in the district was 1.8 acres which is equivalent to 0.73 hectares (Amanor-Boadu *et al*., 2015). Rainfed rice cultivation is the principal activity and source of income for many households in the Yapalsi and Nakpanzoo communities in the Savelugu district, but yet its production is varied from one year to another due to climate variability. Research has shown that the very effective way of building resilience towards climate variability is employing adaptation strategies to manage the situation (IPCC, 2012; Martin-Breed and Anderies, 2011). An attempt to build farmers awareness, resilience through the provision of localized climate services, led to the development of the FSApp to enable farmers to make climate-informed decisions about their agriculture and thereby improve their production practices.

1.2 Methodology

The various methods that were used to achieve the objectives of this research are presented in this section. (Fig. 3.2).

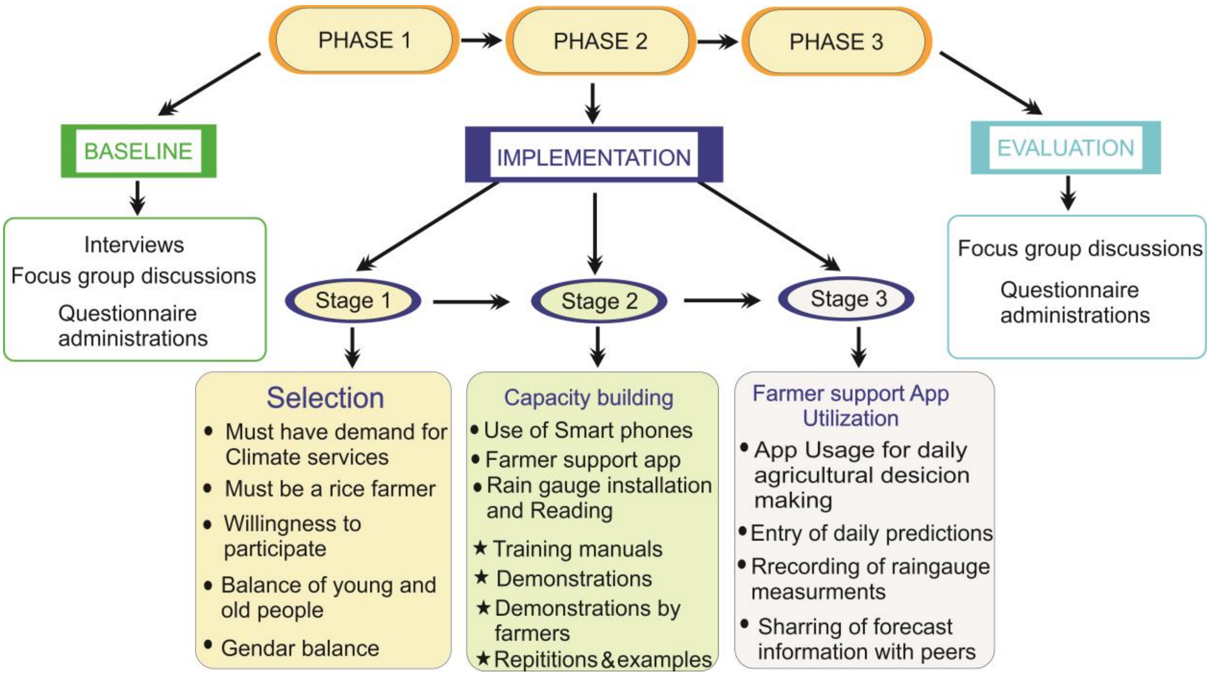


Figure 3.2: Project Methodology Overview

(Source; Dogbey, 2020)

3.2.1 Baseline Studies

A baseline study was done using expert interviews (EIs), focus group discussions (FGDs), and questionnaires (QUs) as shown in Fig. 3.2. The EIs were carried out in organizations that render services (Agronomic, climatic, Financial, Technical, Economic) to rice farmers; the FGDs were done in two communities (Nakpanzoo and Yapalsi) and the QUs were administered to seventy-five farmers, 30 each in Nakpanzoo and Yapalsi communities and fifteen (15) in Diare community. Nine experts were interviewed in the Tamale municipal and two focus group discussions were held per community (Nakpanzoo and Yapalsi). Phase 2 and phase 3 of the study are the main focus of this document and these were carried out from 14th June 2020 to 4th December 2020.

3.2.2 Methodology for the Formation of Climate Groups for the Implementation Phase

Nakpanzoo and Yapalsi are farming communities where most of the individuals are engaged in farming as their main economic activity. Most of these farmers cannot read and write and learn best through field demonstrations. In order for the anticipated outcome of the project to be achieved, it was necessary to use a combination of purposive and snowball sampling methods for the selection of farmers to form climate groups in the various communities. The snowball sampling method (Patton, 2002) was adopted and focused on rice farmers as the principal criteria. For the purposes of recording rainfall data from the rain gauges, at least one farmer in each group could read and write in both communities. The trained farmers were encouraged to also pass on the knowledge to the other farmers during the period of implementation.

The criteria used in selecting the participants for the study included the following;

- Rice farmer; the participant must be a rice farmer or if the participant is a woman, her husband must have a rice farm managed by her as well.
- The farmer must have demand for climate services and also be willing to participate in the project and make himself/herself available for meetings.
- A balance of young and old people; it is known that the most experienced people in the community are the older people. For sustainability purposes, it was necessary to include both young and old people in the training so that the younger ones can learn from the older ones.
- Gender balance; measures were put in place to incorporate gender balancing in the selection process.

3.2.3 Objective I – Farmers' Capacity Building

To build the capacity of farmers to enable them to use the FSApp.

Research question; What are the steps to build the farmers' capacity through the FSApp?

3.2.3.1 Experimental Design - Formation of Climate Groups

Groups of about sixteen (16) farmers were created in both Yapalsi and Nakpanzoo communities, to undertake the training as part of the implementation process. The training and the implementation processes were planned to be completed within ten (10) visits to the community, during the period; 14th June to 5th September 2020 after which monitoring and evaluation took place. Detailed manuals were prepared on the FSApp to facilitate the training process.

3.2.3.2 Capacity Building and Training Sessions for Farmers

The training sessions started by discussing with farmers the various aspects of farming activities that require the use of climate information (land preparation, sowing/transplanting, fertilizer application, pest control and harvesting). We also discussed with farmers the importance of rainfall and sunshine (Temperature) to farming activities and why they needed to have access to more localized weather information as shown earlier in this section. Farmers were also informed on sources and probabilistic nature of scientific forecast information making them understand that scientific forecasts are probabilities that operate on chances of occurrences ranging from (0 – 100%). The closer the probability is to 100% the higher the chances of a rain. Farmers were also made aware that scientific forecasts are predictions and therefore have some margin of error (there are no perfect predictions).

Next, the phones upon which the FSApp was installed for the implementation phase were introduced to the farmers. The basic operations of the phones were demonstrated to them and these included: switching phones on and off, navigation, appropriate handling and maintenance of the phones.

FSApp was introduced to the farmers by telling them how different the app was from the apps that are already in the system. The added advantage associated with this app is that the FSApp predicts weather on the basis of both scientific forecast and indigenous ecological indicators, which tremendously improves its accuracy and reliability. Thus, the app gives them the chance to input their own predictions based on the indigenous ecological indicators as shown in Fig. 3.2.

3.2.3.3 Training on the FSApp

The training was conducted in the form of demonstrations with the assistance of a translator to translate to and from the local language (Dagbani). The program started by describing the various taps and features of the App to the farmers. Farmers were shown how to navigate through the App and browse through the various tabs, moving from one menu to the other. Next, farmers were shown how to enter predictions into the App, using indigenous ecological indicators which forms the local forecast component of the App. A detailed manual was used to facilitate the training. All features of the FSApp were clearly illustrated to guide the farmers through the various processes and functions of the App. The manual contained more pictures and figures and less text to facilitate easy understanding by farmers. Details of the training manual are shown in appendix A.

3.2.4 Objective II - Skills Assessment

To assess the accuracy of the FSApp predictions in relation to the ground truth.

Research question; What are the skills of the FSApp in terms of accuracy in predicting the weather in relation to the ground truth?

This objective was addressed by performing a skill assessment analysis of the FSApp. This entails a comparison between the actual climate conditions and the weather forecasted with the FSApp which includes an integration of scientific forecast and local forecast. Microsoft Excel was used to perform this analysis.

3.2.5 Objective III - Evaluation

To evaluate the impact of the App with regards to low land rice farming.

Research qquestion; What are the advantages of the FSApp uptake as related to the farmers' decision-making and agricultural practices?

The implementation of the app spanned 10 weeks, starting from the 14^{th} of June 2020 to the 5^{th} of September 2020. As part of the implementation and beyond, periodic surveys were conducted to monitor implementation and assimilation by farmers. Structured questionnaires were administered to farmers to evaluate the usefulness of the developed FSApp to their farming activities, whether it has improved the farmers' decision-making, how trustful the integration of scientific and local forecast is, what the implications from using the APP are, how the APP can be further improved and what impact the App had on the rice farming activities. All farmers involved in the study were interviewed for purposes of evaluation. In performing this evaluation analysis, emphasis was placed on behavioural change of farmers after they have been trained to use the FSApp. FGDs in addition provided the required data for the analysis. These approaches according to Tall *et al*., 2018 have been very effective in analysing the impact of such projects on farmers behavioural changes, hence can be adapted to determine the extent to which decisions pertaining to agricultural activities have changed following the training and use of the FSApp for predicting the weather, and to identify limitations in the delivery and use of climate information.

3.2.5.1 Data Collection for Evaluation (FGDs and QUs)

Before implementation of the FSApp was done in the two (2) Communities, a base-line study was carried out where FGDs and QUs were used in these two (2) communities to capture information on farmers' access to weather information, traditional knowledge on weather and climate, adaptions to flood and drought occurrences and local parameters used in identifying weather conditions. Also, at the end of the FSApp implementation, FGDs and QUs were used in the Nakpanzoo and Yapalsi communities to evaluate the effectiveness of the training process, the effect of the FSApp implementation on the adoption of the FSApp and it's impact on the use and behavioural changes among farmers as a result of using the FSApp.

QUs were administered to all members of the climate group. In order to avoid any form of bias in relation to gender pertaining to the evaluation, two (2) FGDs were held in each community, separately for men and women members. This was meant to allow the women to speak freely and to allow the project team to get a balanced response on the outcome of the project. The attendance of the final evaluation focus group discussion was opened for all farmers in the community and not the members of the climate group alone. This was done to ensure that the views and experiences of other farmers were captured in the evaluation of the outcome of the project. This was to provide a detailed evaluation of the project in the valleys.

1.3 Materials

Research of this nature requires the use of various materials, tools, and techniques. The major materials and tools required to successfully carry out the implementation and assessment of the FSApp, "which is a tailor-made mobile app designed to deliver localized climate services (rainfall information) to farmers in their various communities to address their specific needs with regards to rainfed, low-land rice farming", are presented as follows;

Smart phones (Model; BG2-U01): These were android devices upon which the FSApps were installed for the implementation processes in the various communities. Mobile phones were given to each community viz; Nakpanzoo and Yapalsi where training manuals were prepared to teach farmers. starting from how to navigate through the mobile phones, download the FSApp from the google play store, install it and finally use it for daily forecasting and decision making.

Rain Gauges: Two standard rain gauges were installed in each project community to monitor rainfall in these communities. The farmers were involved in the installation of the rain gauges and were also trained by the research team on how to measure, record rainfall data (rainfall depth (mm)) and also maintain the rain gauges to be used from season to season even after the project has ended. Rain gauges were left in the care of the team leaders of each climate group. Taking of daily rainfall measurements were assigned to two (2) people in each community.

3.4 The FSApp

The FSApp is a tailor-made android mobile App developed to be used as a basis of decision making in agriculture activities that rely on weather and climate. The FSApp was initially designed specifically to the Ghanaian context and in the future, it is envisaged to be implemented in several farming communities of the world to assist small-holder farmers with farm decision making in relation to weather and climate.

The FSApp predicts on the basis of both scientific and indigenous forecast and according to Gbangou *et al* 2021, produces an improved forecast in terms of accuracy in predicting the ground situation. The FSApp incorporates Local Forecast Knowledge (LFK) and Scientific Forecast Knowledge (SFK), and it displays those in the hybrid forecast section within the FSApp. This FSApp was designed to give users the chance to input their own predictions based on the available indigenous ecological indicators hence the farmers in the various communities are trained to add their forecast and their assessment of the probabilities (low, medium, high) of rainfall and sunshine based on various key climatic Indigenous ecological indicators. Gbangou *et al*. (2021) documented the various LFK-indicators through FGDs and in-depth interviews with Farmers at Ada, East District, Ghana. By using this methodology, farmers from five (5) communities identified twenty-two (22) indicators related to weather timescale prediction and twelve (12) indicators used for seasonal timescale predictions. The documented indicators relate to different features of atmospheric conditions (clouds, wind and dews), celestial elements (sun, sky and moon), fauna (ant, frog, bird, goat, scorpions, worms and pig) and flora (tree). From Gbangou's study, the various indicators were carefully selected as shown in Fig. 3.3 to develop the local forecast section of the farmers support app which farmers base daily forecast inputs on. These indicators are eight (8) namely; "Dark clouds seen; scorching Sun; strong wind blowing W-E direction; specific bird making sounds; ants carrying eggs/food into a hole; a lot of dews observed; red circle around moon sun; frog croaking a lot". The same FSApp was used for study in Savelugu communities after some adjustments.

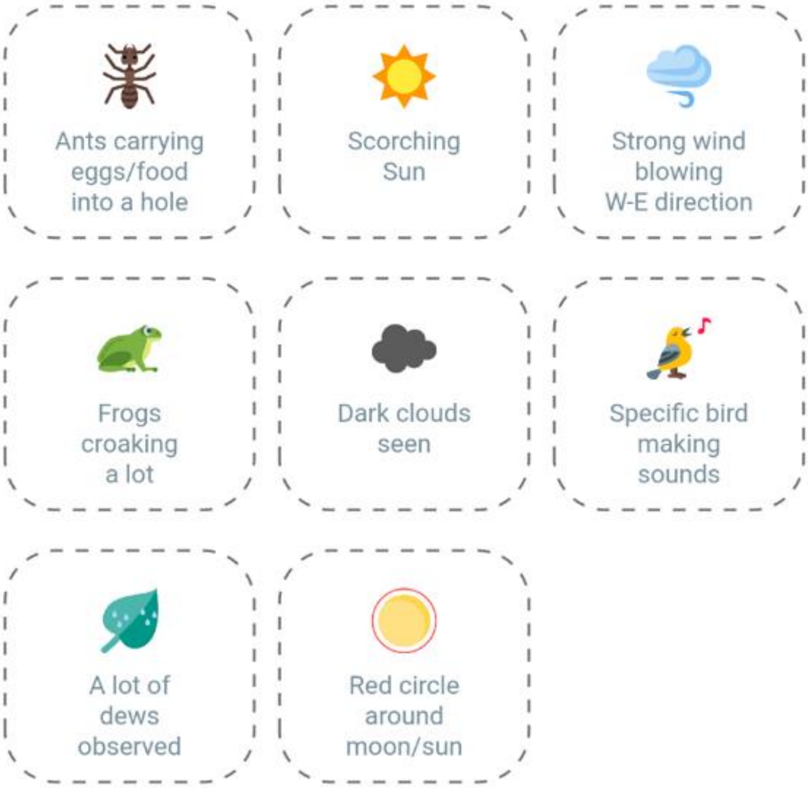


Figure 3.3: Various Ecological Indicators from which Farmers are to Select from Based on the Prevailing Situation

(Source: FSApp; Dogbey, 2020)

3.4.1 The Scientific Forecast Section of the FSApp

The basis for the scientific predictions is centred on forecast provided through an API: URL from meteoblue weather provider embedded in the FSApp. The scientific forecast section is categorised into 1-day, 7- days and 14- days forecast, respectively, as depicted in the FSApp and also displays the following information; total precipitation (mm), rainfall probability (chance of rain) (%), wind speed (ms^{-1}), minimum temperature (°C), maximum temperature (°C) and mean temperature (°C).

The FSApp was designed to possess specific features to make it accessible to farmers at all levels. These features included; simple design, audio feedback, pictorial and colourful view and easy navigation.

3.4.2 FSApp Interface

Fig. 3.4 is the first page to see when you start the FSApp. By sliding left, you move to the pages respectively displayed in Fig. 3.5.

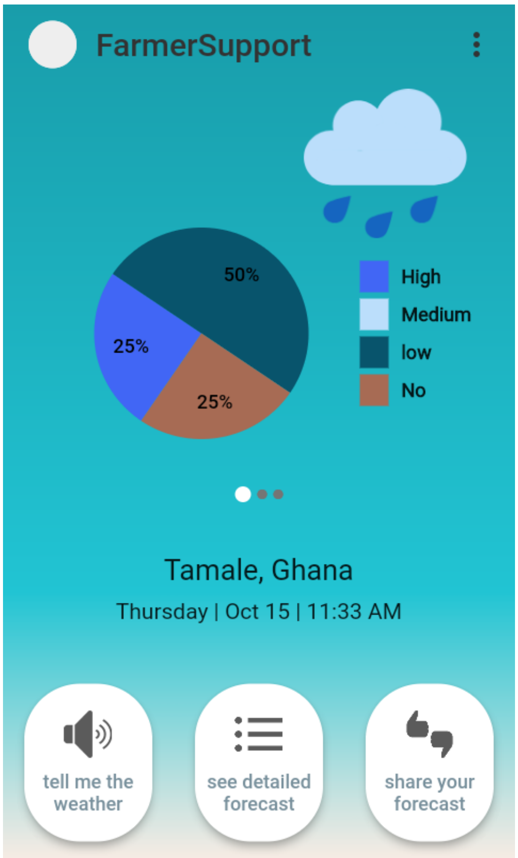


Figure 3.4 Home Page of FSApp Showing the Various Taps and Rainfall Probability as Predicted by Farmers

(Source: FSApp, Dogbey, 2020)

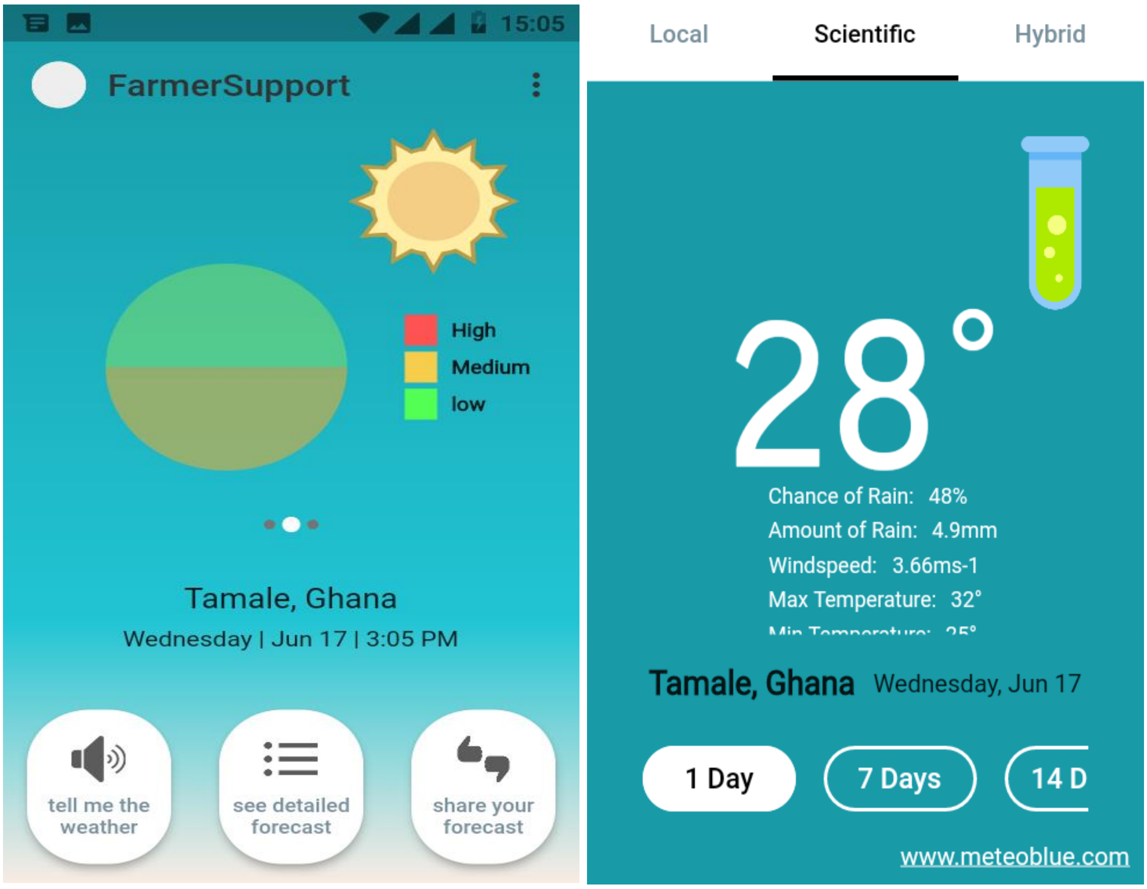


Figure 3.5: Intensity of Sunshine as Predicted by Farmers (Left) and Rainfall Probability, Depth, Temperature and Windspeed as Provided by meteoblue (right)

(Source: FSApp; Dogbey, 2020)

3.4.3 Features of the FSApp

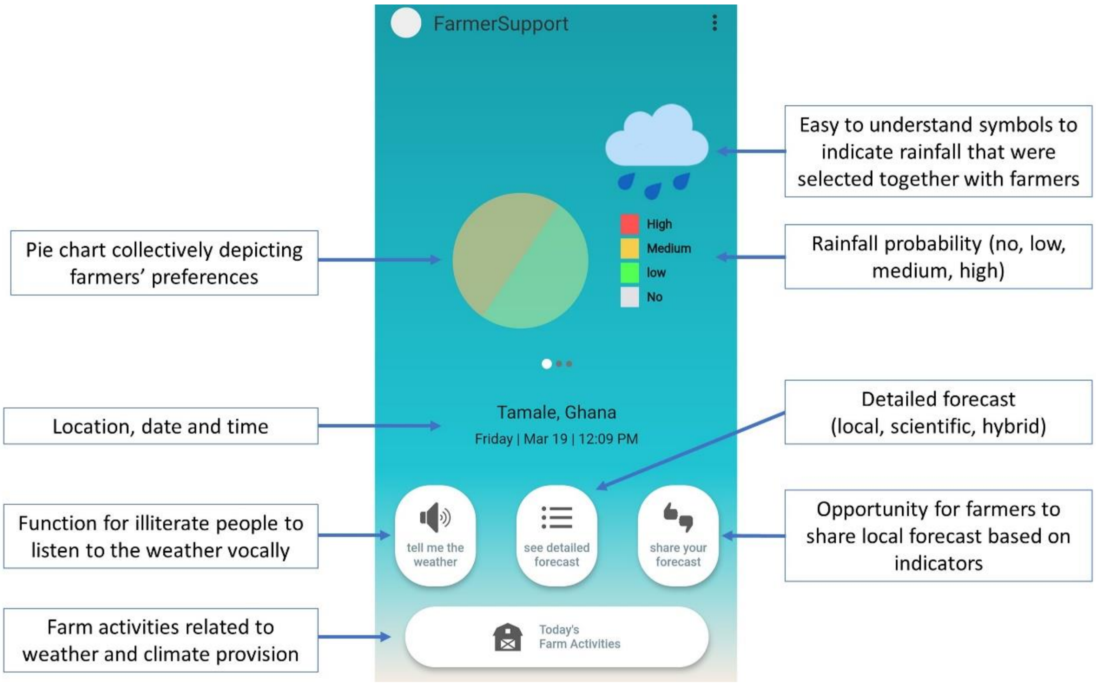


Figure 3.6 Features of the FSApp

(Source: FSApp; Dogbey, 2020)

FSApp windows A and B shown in Fig. 3.6 show a summary of the probability of rainfall and sunshine intensity, respectively, as predicted by the farmers using indigenous indicators that were introduced in Fig. 3.3. For example, if the greater proportion of the farmers think there will be rainfall, then the colour associated with the level of rainfall that the farmers had predicted will take the greater proportion of the pie chart as it is happening in window A where the 'low rainfall probability' has been selected by most of the farmers and is depicted with dark blue colour (50%).

3.4.4 Detailed Forecast

The detailed forecast FSApp pages are respectively shown in Fig. 3.7. The first page (left) showed the local forecast where farmers forecast inputs and probabilities are recorded and displayed text and Figures (chart). In the middle, the scientific forecast page is displayed, followed by the hybrid forecast on the right side.

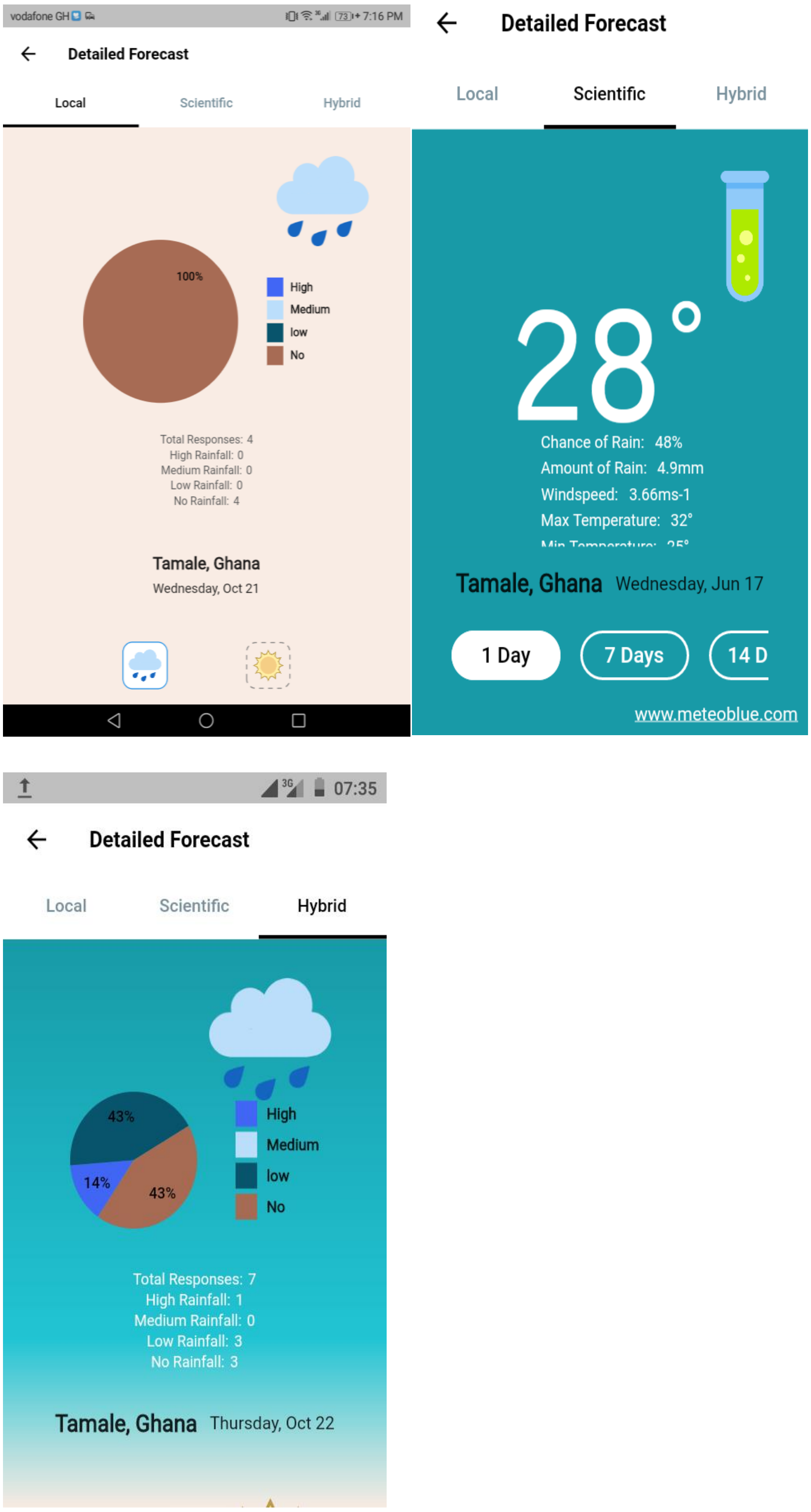


Figure 3.7: Local (left), Scientific (middle) and Hybrid Forecast (right) on the FSApp Interface

(Source: FSApp; Dogbey, 2020)

3.4.5 Scientific Forecast

As shown in Fig. 3.8, "1-Day" forecast displays the weather in terms of temperature (°C), rainfall amount (mm) and the probability of rainfall for that particular day. The 7-Days forecast displays the weather for the next 7 days. The 14-Days forecast displays the weather for the next 14 days. The 7-Days and 14-Days forecast will enable the farmers to plan farming activities 7 days and 14 days ahead respectively. But it should be noted that the more the predictions are into the future the lesser the accuracy of the prediction therefore, the 7 day and 14 day predictions will be less accurate compared to the 1 day prediction. (Paparrizos *et al.*, 2020). Ranking the accuracy of predictions from lowest to highest; 14 day – 7 day – 1 day.

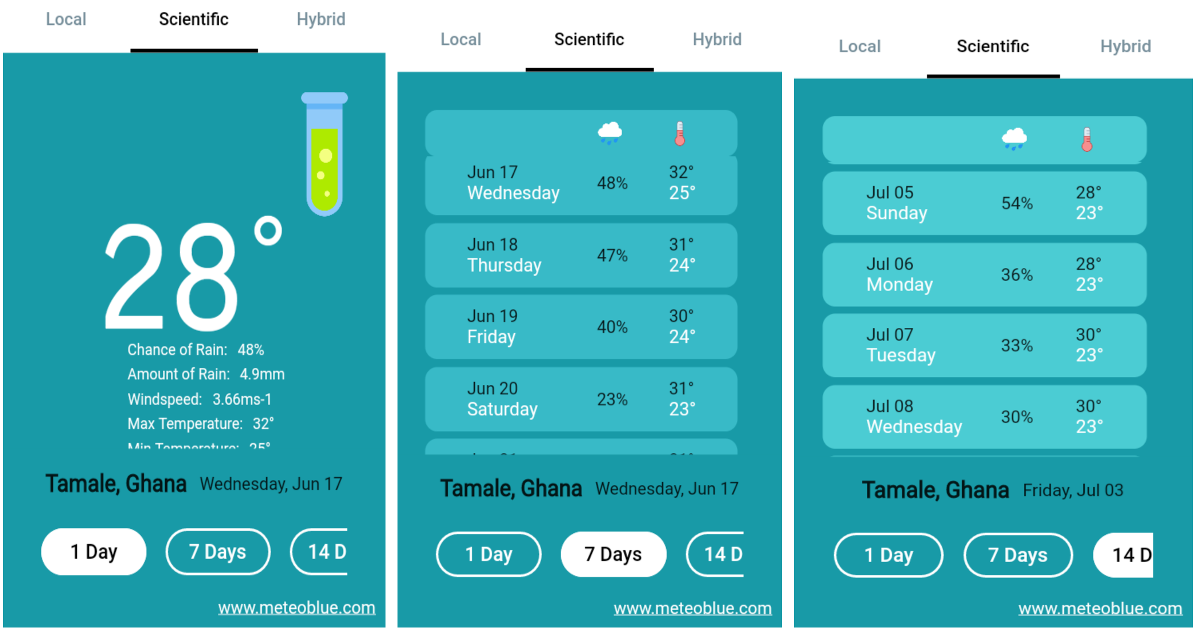


Figure 3.8 Scientific Forecast Page Depicting 1-Day (left), 7-Days (middle) and 14-Days (right) Forecast Respectively

(Source: FSApp; Dogbey, 2020)

3.4.6 Hybrid Forecast

The hybrid forecast page displays both scientific forecast and local forecast from which the farmer can now proceed to make a final decision on whether or not to carry out a climate dependant activity on the farm. It should be noted that at the moment, the hybrid forecast is not thoroughly developed yet, thus the current thesis will focus on the local and scientific forecasts provision.

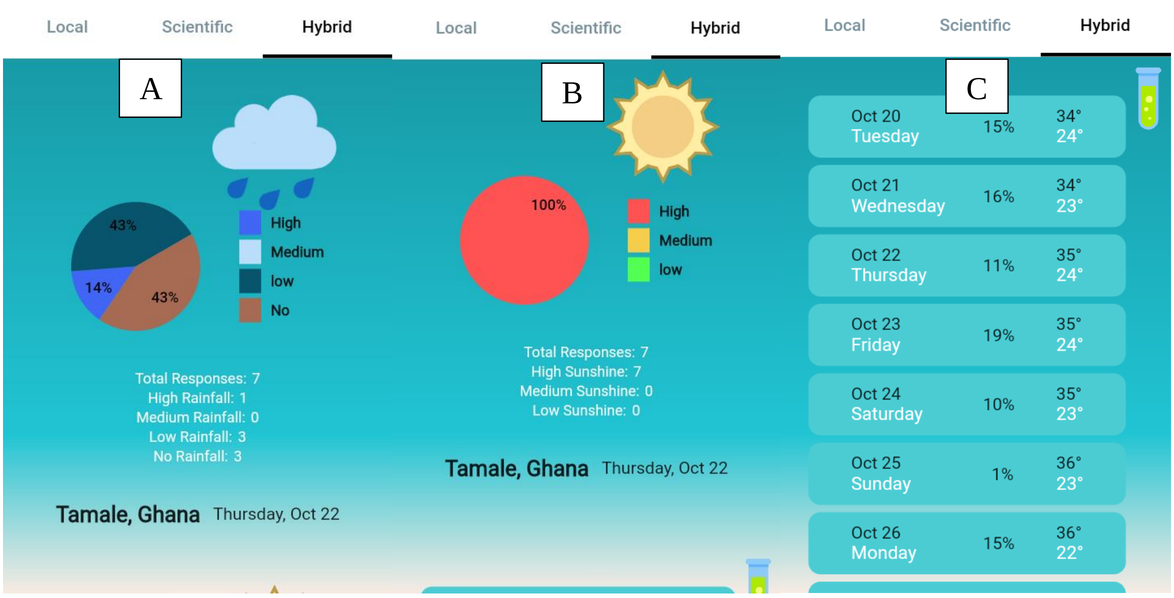


Figure 3.9: Hybrid Forecast Page Displaying Both Scientific (C) and Local Forecast Probabilities (A & B)

(Source: FSApp; Dogbey, 2020)

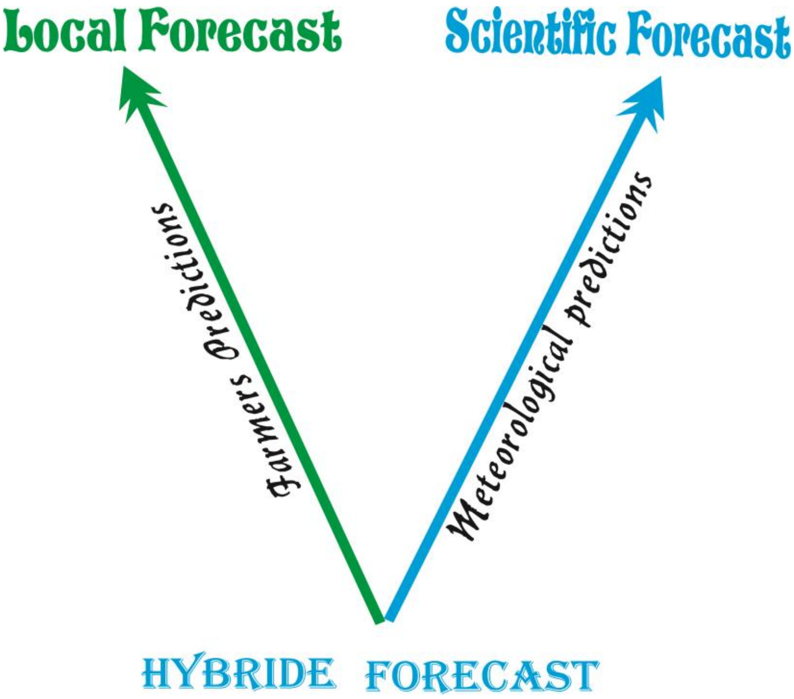


Figure 3.10: The Hybrid Forecast Sections Presents a Combination of the Local and Hybrid Forecast

(Source: Dogbey, 2020)

3.5 Data

The dataset used for the analysis ranged from August 1, 2020, to October 31, 2020. These data included the following;

3.5.1 Rainfall Data from the Rain Gauges

Farmers in the two (2) valleys i.e. Nakpanzoo and Yapalsi were provided with two standard rain gauges each, making a total of four (4) rain gauges across the two (2) valleys. The farmers were trained by the research team on how to set up the rain gauges, measure and record rainfall data (rainfall depth (mm)) and also maintain the rain gauges for sustained use. Farmers took readings from the gauges from 6th June to 31st October 2020. For the purpose of this research, gauge data ranging from August 1, 2020 to October 31 2020 were selected for analysis. Daily rainfall data was recorded over 5 months, and three months of data were selected for the analysis that is, 92 days starting from August 1, 2020 to October 31, 2020. These localized rain gauge readings were used as a reference point to investigate how close the predictions from both the local people and meteoblue forecast are to the real situation on ground. Therefore, revealing the skilfulness of predictions from the mentioned sources.

3.5.2 Local Forecast Knowledge Data

Farmers were selected and put into groups of 16 on average, in the two (2) experimental communities. A total of 21 farmers out of this group entered their daily predictions into the FSApp by observing local indicators in their surroundings. Daily forecast entered by farmers into the FSApp was stored on a server throughout the implementation period and retrieved for analysis at the end of the season. The data includes the following; sunshine indicators, level of sunshine (low, medium or high), rainfall indicators, status of the level of rainfall (low, medium, high or no rainfall) and finally, whether it will rain on a particular day or not.

3.5.3 Scientific Forecast (meteoblue datasets)

Two (2) different sets of scientific weather forecasts data were obtained from meteoblue, that is the meteoblue dataset and the scientific forecast probabilities. Only the meteoblue dataset was used for the analysis. The data set obtained from meteoblue was presented in hourly resolution which was then aggregated to daily resolutions to suit the analysis.

meteoblue is a meteorological service that offers weather prediction in a graphical summary for any arbitrarily chosen location on Earth. Besides that, it predicts the weather for several continents on scales not available from other weather services, Both Non-Hydrostatic Mesoscale Models (NMM, developed by NOAA) and the NOAA Environment Modeling System (NEMS) are used for weather predictions. NEMS is a multi-scale model (used from global down to local domains) and significantly improves cloud development and precipitation data. Weather services are publicly available, supported by ads, on its website (meteoblue, 2018). meteoblue forecast combines more than 25 different weather models to achieve the highest degree of precision worldwide. Various state-of-the-art technologies are employed to combine the latest observation data and weather models to achieve the highest accuracy. Daily aggregated forecasts were used as an illustrative scientific forecast. These datasets were retrieved and verified against gauges data which was collected over the 92-day active FSApp utilization period, ranging from August 1, 2020, to October 31, 2020.

3.5.4 Data for Evaluation Analysis

These data included information from the baseline study and the final evaluation data collected after the implementation processes. FGDs and QUs were administered to the two (2) communities (Nakpanzoo and Yapalsi) to collect data on farmers' access to weather information, traditional/indigenous knowledge on weather and climate, adaptions to flood and drought occurrences and local parameters used in identifying and interpreting weather phenomena. At the end of the FSApp implementation, the FGDs and QUs administration were used to evaluate the effectiveness of the training process and the effect of the FSApp implementation on the adoption of the FSApp and its impact on farmers decision making and behavioral changes towards their farming practices.

3.6 Data Analysis

3.6.1 Skills Analysis of Local and Scientific Forecasting Knowledge

The quantitative skills of LFK-indicators and SFK-meteoblue against reference gauge data were assessed using a contingency table (Table 3.2). This table was used to compute the most relevant skill metrics, such as the probability of false detection or false alarm rate (POFD), the probability of detection or hit rate (POD) and the Hanssen-Kuipers (H-K) discriminant skill score as described in Gbangou *et al.* (2021). These metrics work well together and allow for a complete analysis of the performance of forecasts data (Gbangou *et al.*, 2021). H-K skill score (Hanssen and Kuipers, 1965) measures the ability of the LFK-predictions or/and SFK-forecast to discriminate the occurrence of rainfall events (i.e. yes rain) and non-events (i.e. no rain). Skills scores were computed for individual LFK-predictions, SFK forecast and the integration of LFK and SFK.

H-K = POD – POFD with POD = $\frac{a}{(a+c)}$ and POFD = $\frac{b}{(b+d)}$ (Equation 1)

Where: H-K is the Hanssen-Kuiper's discriminant or Pierce Skill Score (Hanssen and Kuipers 1965); POD and POFD represent, respectively, the probability of detection or hit rate and the probability of false detection or false alarm rate; H-K ranges from -1 to 1; H-K ≤ 0 indicates no skill, H-K =1 is the perfect score; a, b, c and d are shown in Table 3.2.

Holding the rainfall data collected from the rain gauges in the various communities (Nakpanzoo and Yapalsi) as the reference, the various forecast components (LFK, SFK, integration Scenario One (IS-one) and integration Scenario Two IS-two) were scored against the Rain gauge data from the communities (reference), respectively. The LFK data was obtained from farmers input into the FSApp whilst the SFK was obtained from meteoblue. Only 1.0 mm and above forecast data from meteoblue was considered as a rain event to be used for the analysis.

Table 3.2: Contingency Table for Categories of Events

	Event-observed	Event-not observed	Total
Event-forecasted	Hits (a)	False alarms (b)	Yes forecasted (a + b)
Event-not forecasted	Misses (c)	Correct rejection (d)	No forecasted (c + d)
Total	Yes observed (a + c)	No observed (b + d)	Total forecasts (n)

(Source: Gbangou *et al.,* 2021)

3.6.2 Skills Analysis of Integrated/Combined Forecast (Local and Scientific)

The analyses in this section focused on combining LFK and SFK. Each SFK system was therefore considered (i.e. meteoblue) as an additional forecast to the LFK predictions and applied a similar analytical approach described in section 3.6.1 to evaluate the skills of the integration.

3.6.3 Evaluation of the Training and Implementation Processes

Ms-Excel programme was used to analyse the data from the FGDs and the QUs that were administered. Comparisons were made to access the outcome of the implementation, using the baseline information as the reference (control).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Skill Assessment Analysis

The skills analysis of the performance of LFK, SFK and its integrations was done to assess the skills of the FSApp in predicting the weather in relation to the ground truth using the Hanssen-Kuipers discriminant or Pierce Skill Score (H-K Score).

4.1.2 Analysis of Performance of Local Forecast Knowledge

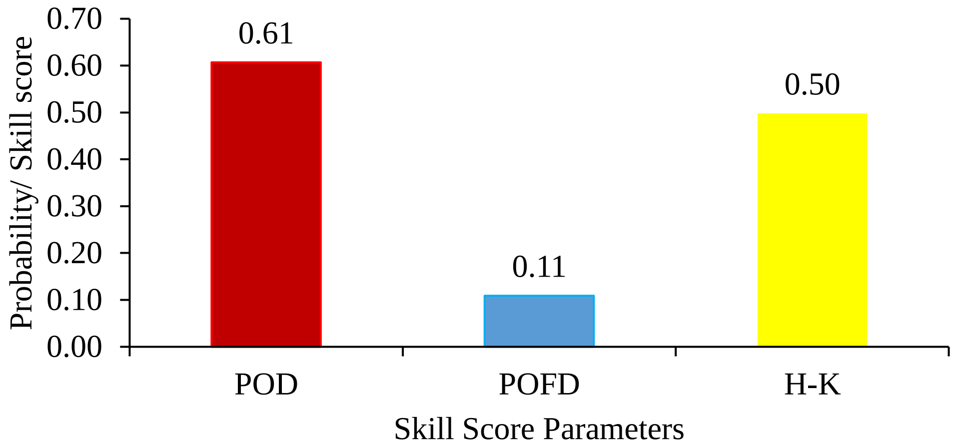


Figure 4.1: Skills of the Local Forecast Knowledge Section of the FSApp

(Source: Dogbey, 2021)

The results of the analysis as seen in Fig. 4.1 portray a high hit rate (POD) of 0.61 and a significant false alarm rate (POFD) of 0.11 which feather reduced the hit rate yielding an H-K-score of 0.50 which is a fairly good score, consistent with Gbangou *et al.*, 2021 who recorded the highest H-K score for the LFK to be 0.56.

4.1.3 Performance of Scientific Forecast Knowledge (meteoblue)

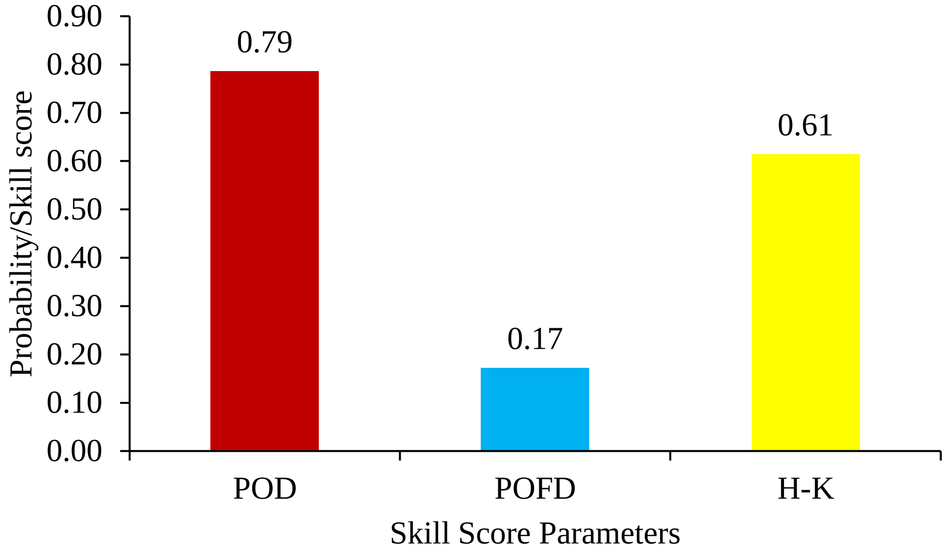


Figure 4.2: Skill of SFK Section of the FSApp

(Source: Dogbey, 2021)

The skills analysis of the scientific forecast involved the use of scientific forecast data (from 1 mm and above) obtained from meteoblue and the rainfall data collected from the 2 project communities over a ninety-two (92) days period. After running the skills analysis, a high POD value was obtained with a significant value for POFD resulting in a very good H-K score of 0.61 as shown in Fig. 4.2. an H-K-score of 0.61 shows a very high accuracy level of predicting the real situation on ground.

4.1.4 Performance Assessment of the Integration between SFK and LFK

4.1.4.1 Integration Scenario One (IS-one) ((0, 1 = 1)*(1, 0 = 1))

Under integration scenario one, if both scientific forecast and local forecast are positive then we consider as a rainfall event; if both scientific and local forecast are negative we consider a non-rain event; if the scientific forecast is positive for a rainfall event and the local forecast is negative, it will be considered as a rainfall event and if the scientific forecast is negative and local forecast is positive we consider as a rainfall event as well.

Let say;

Scientific forecast positive = 1

Scientific forecast negative = 0

Local forecast positive = 1

Local forecast negative = 0

Where 1 represent a rainfall event and 0 stands for no rainfall event

Integration scenario One

1+1 = 1

1+0 = 1

0+1 = 1

0+0 = 0

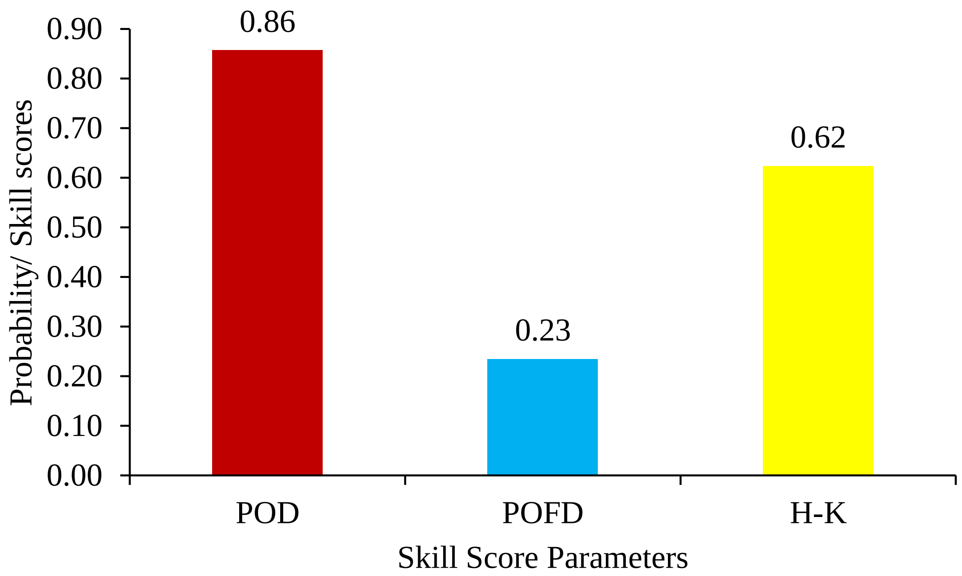


Figure 4.3: Skill Scores of the Integration between SFK and LFK (IS-one)

(Source: Dogbey, 2021)

Integration scenario one functions on the assumption that whenever there is a combination of a non-event (0) and an event (1) the results should always be positive (event-1). When this integration was run against the reference (Rain Gauge data) the results showed a very high POD value of 0.86 and an equally high PODF value which reduced the POD value yielding an H-K score of 0.62 as presented in Fig. 4.3.

4.1.4.2 Integration Scenario Two (IS-two) ((0, 1 = 0)*(1, 0 = 0))

Under integration scenario two, if both scientific forecast and local forecast are positive then we consider as a rainfall event; if both scientific and local forecast are negative we consider a non-rain event; if the scientific forecast is positive for a rainfall event and the local forecast is negative, it will be considered as a non-rainfall event and if the scientific forecast is negative and local forecast is positive we consider as a non-rainfall event as well.

Let say;

Scientific forecast positive = 1

Scientific forecast negative = 0

Local forecast positive = 1

Local forecast negative = 0

Where 1 represent a rainfall event and 0 stands for no rainfall event

Integration scenario two

1+1 = 1

1+0 = 0

0+1 = 0

0+0 = 0

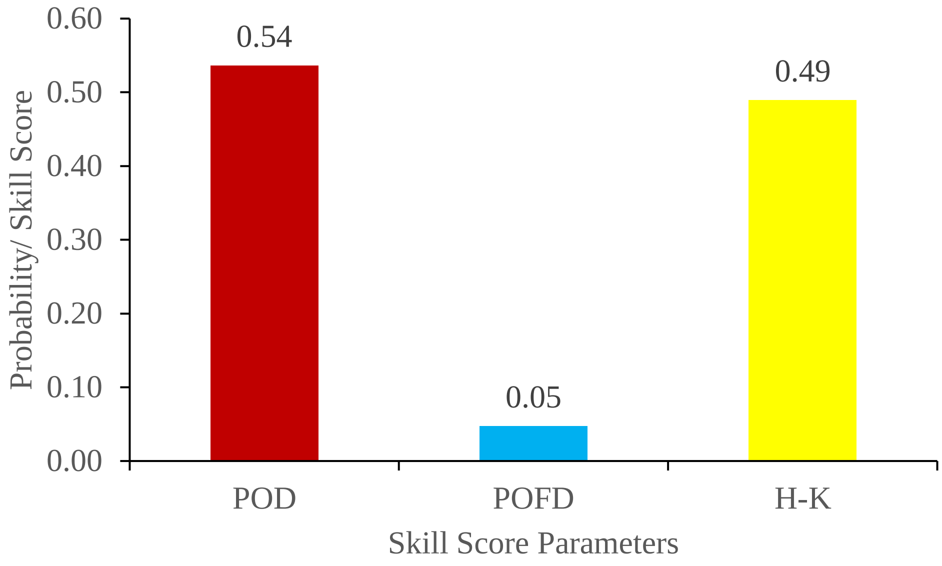


Figure 4.4: Skill Scores of the Integration between SFK and LFK (IS-two)

(Source: Dogbey, 2021)

Alternatively, a second scenario (IS-two) which functions on the assumption that whenever there is a combination of a non-event (0) and an event (1) the results should always be negative (event-0) was used for the skill score analysis. When this integration was run against the reference (Rain Gauge data) the results showed a POD value of 0.54 and a PODF value of 0.05 which reduced the POD value yielding an H-K-score of 0.49 as shown in Fig. 4.4.

4.1.5 Trend Assessment of LFK, SFK, IS-one and IS-two

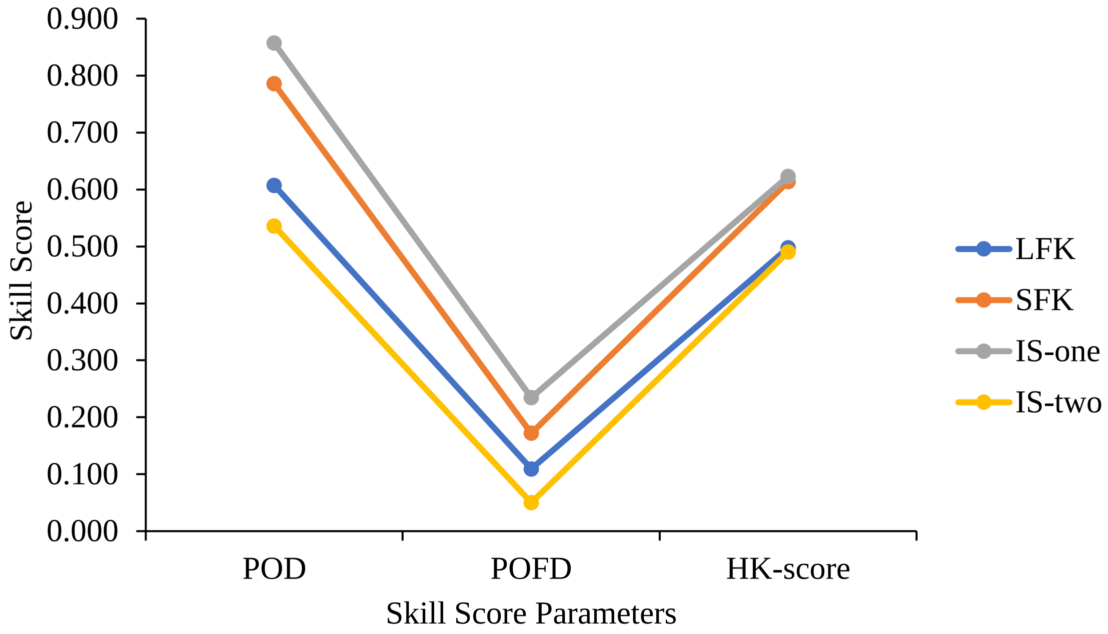


Figure 4.5: Skill Scores of LFK, SFK, IS-one and IS-two

(Source: Dogbey, 2021)

Fig. 4.5 presents the results of all four analyses, clearly showing the trend of the skill scores of each analysis. Rating from highest to lowest, it can be seen that integration scenario one had the highest skill followed by scientific forecast knowledge, local forecast knowledge and the lowest by integration scenario two, respectively. The difference between the scores of SFK and IS-one is 0.01, which is almost negligible. IS-two recorded the least score making it less important in the skills analysis i.e IS-one should be considered over IS-two.

4.1.6 Rating of the Most Frequently Used Indigenous Ecological Indicators for LFK

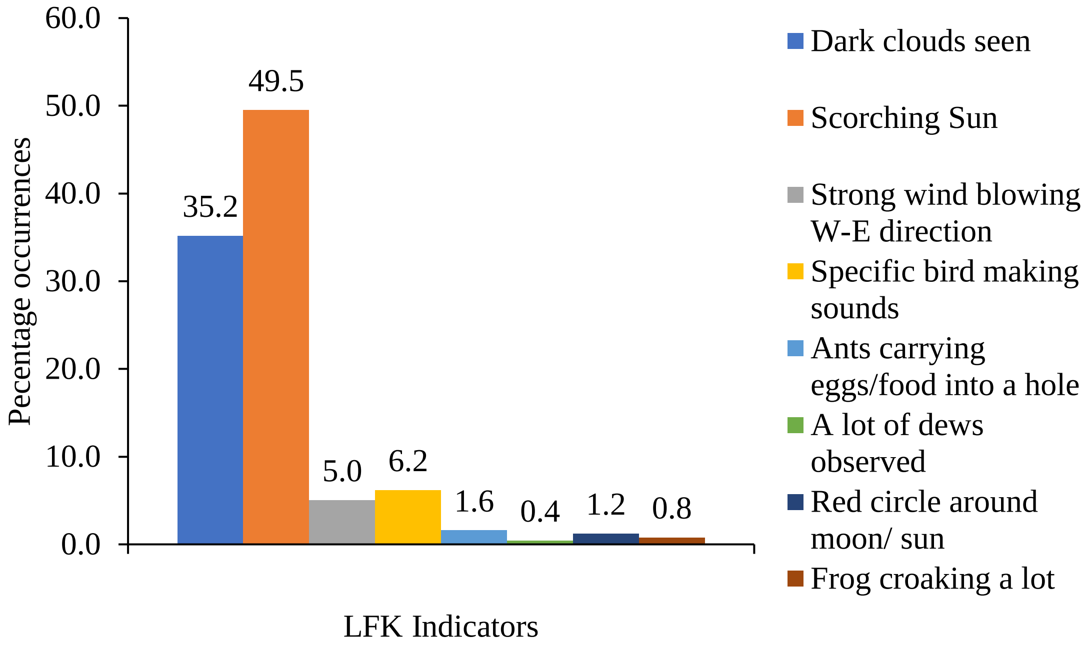


Figure 4.6: Rate of Occurrences of LFK Indicators

(Source: Dogbey, 2021)

Analysis of the eight indicators were performed to investigate the most frequently used indicator for rainfall predictions over the ninety-two (92) days period. After the analysis, it was revealed that the most frequently occurring indicator was “scorching sun” followed by “dark clouds seen” and “a lot of dews observed being the least observed indicator as shown in Fig.4.6. this trend indicated that most of the farmer's observations for daily forecast inputs were based more on celestial bodies for the ninety-two (92) day rainy period.

4.1.7 Final Evaluation on the Training and Implementation of the FSApp

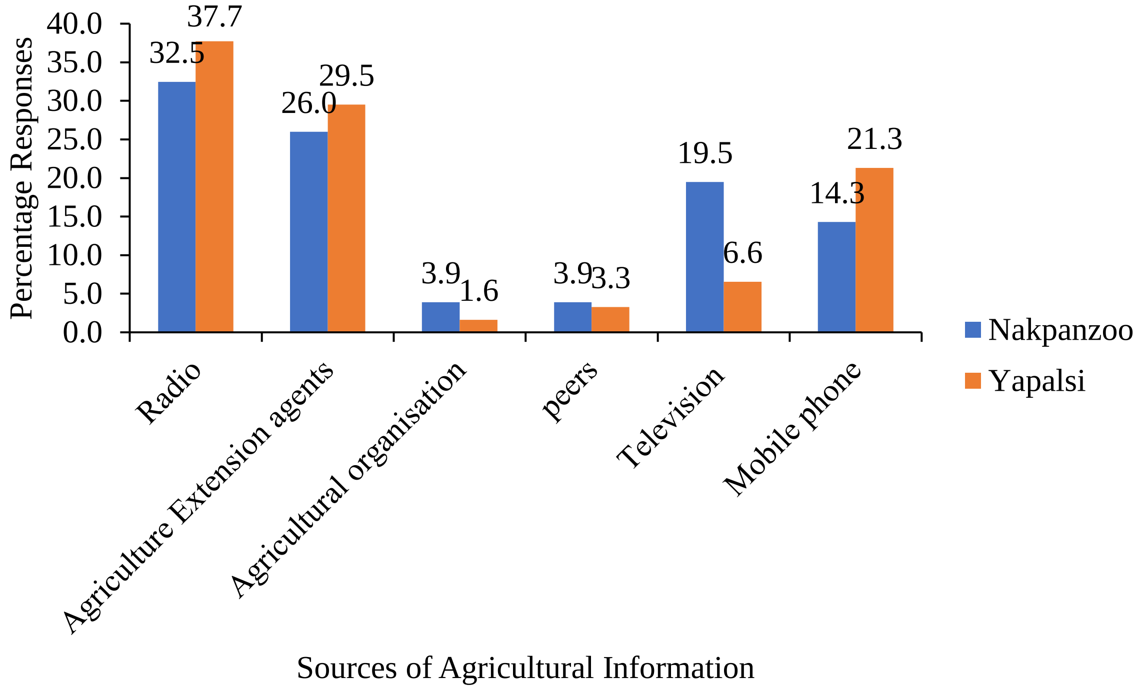


Figure 4.7: Platforms Being Used to Access Forecast Before the Implementation of the FSApp in the two (2) Communities

(Source: Field survey, 2020)

4.1.8 Nakpanzoo community

4.1.9 Suitability, Adoption and Adaption of the FSApp for Farmers Decision Making in Agriculture

The farmers expressed a very high level of satisfaction with the training and the use of the FSApp. Farmers seemed to be very knowledgeable about climate phenomena after the training. Farmers were able to avoid situations like waste of fertilizer and chemicals for weeds and insect pest control due to the rainfall information they had from the FSApp. It was revealed that the farmers capacity on the use of smartphones, the FSApp and the alertness of the farmers about their environment had increased after the training. The farmers acknowledged the fact that the training had improved their capacities in understanding and interpretation of both local and scientific forecast phenomenon. The farmers mentioned that they were not capable of navigating through a smartphone before the training.

The farmers observed that the daily forecast section of the FSApp was very reliable claiming that its predictions hardly miss but they didn't observe this same accuracy level with the 7 and 14-day forecast sections.

The women farmers found the training to be very educative, expressing their interest in the use of a smartphone for the first time and also the ability to understand and input forecast and interpret the scientific forecast probabilities.

4.1.10 Co-production and Behavioural Change

Before the implementation of the FSApp, farmers either relied on their experiences and instinct to forecast the weather locally or information received from the radio or television about the state of the weather on a particular day. Information is often late reaching farmers. Co-production, where farmers observation and scientific forecast information are integrated by the farmer for decision making has improved the access and availability of forecast information. The hybrid nature of the FSApp (combining LFK and SFK) had increased the confidence of the farmers in forecast provided by the FSApp. Since farmers have to enter predictions into the FSApp, they are encouraged to visit the FSApp on daily basis.

A participating farmer, Mrs Sanatu Mohammed specifically thinks that the early adoption of the app in the Nakpanzoo community was partly due to the inclusion of women in the implementation. The women applied the knowledge from the FSApp in almost all their farming activities. There were days that the women had to postpone their plans of going to fetch firewood in favour of working on the rice farm.

4.1.11 Platforms that are Being Used Currently for Forecasts Information

The farmers are currently using the FSApp to obtain rainfall information. After they were trained to use the FSApp, they have found information from the FSApp to be more reliable than other sources. The women mentioned that the phone is the closest device to them nowadays and also it is very convenient since they can access information at any time with no limitations, as compared to the previous platforms which are not including the community input. At the local forecast section of the present FSApp, farmers are required to input forecast individually and this encourages them to visit the FSApp every morning before going on with their daily activities. According to Mr Sulemana Adams, Mohammed Issah and Baba Mohammed including all farmers in selected communities, there have been several occasions where service providers like Vodafone called to give them weather information. The farmers claimed that this information came late and most often when the rains had already started. These farmers had prepared to receive the rains using information from the FSApp. It was also brought to our notice by the farmers that the traditional rainmaker in the community, a repository of traditional practices, was not available most of the time and thus, was not a reliable source of information for planning on a daily basis. The FSApp according to the farmers is currently the most reliable source of information about the rains.

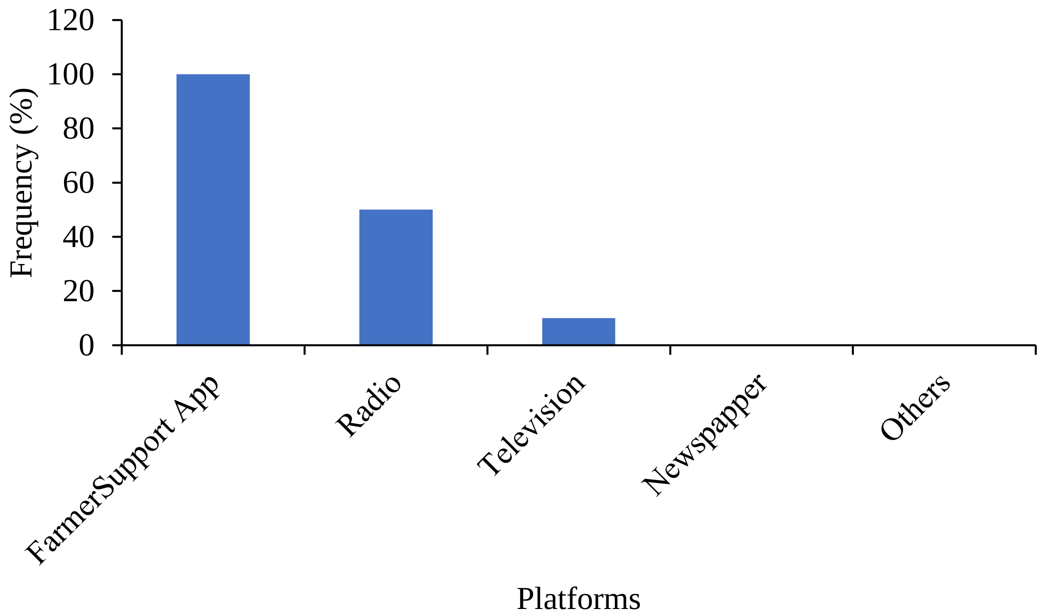


Figure 4.8: Platform Preferences After the FSApp Implementation

(Source: Field survey, 2020)

All the farmers included in the group are currently reliant on the FSApp for their daily weather needs (Fig. 4.8). About 50% of the farmers mentioned that they still listen to the radio for weather information with which they compare the information from the FSApp with 10% of the farmers still watch the television for weather forecast information. However, farmers claim that they no longer pay much attention to forecasting information from the newspaper and network providers.

4.1.12 Suitability and Level of Satisfaction Derived from the FSApp Relative to the Previous Platforms

The farmers expressed a very high level of support to using the FSApp. They find the FSApp to be reliable compared to the sources of information they had access to earlier. The use of the tablets for the forecast makes it more convenient, reliable and suitable and this is because the farmers are involved in the generation of the forecast information. For this reason, the farmers seem to prefer the entire package such as the app and the tablet relative to the other platforms. The use of the FSApp also serves as a means of bringing the farmers together every morning for forecast entries. The FSApp generates localized information to suits the specific needs of farmers and also since farmers don't have to wait to receive weather information from the FSApp relative to previous sources, they feel like the FSApp is more dependable since they can generate and have access to forecast information at any time suitable to them. The women use forecast from the FSApp not only for agricultural activities but also for going to the market, selling at the roadside and other activities and they expressed a very high level of satisfaction with the FSApp.

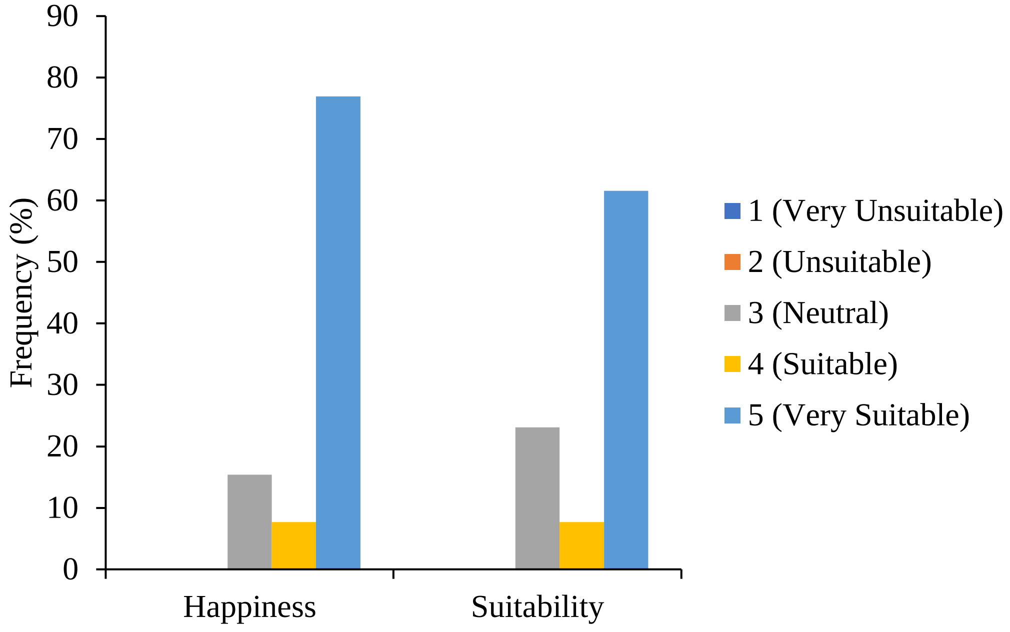


Figure 4.9: Rating of Happiness and Suitability of the FSApp in Farmers' View

(Source: Field survey, 2020)

The majority of farmers expressed very high levels of happiness (77%) and suitability (62%) of the FSApp, as shown in Fig. 4.9. As shown in Fig. 4.9, based on the Likert scale used (1-5) no farmer scored the suitability of the FSApp below 3, indicating that the least score recorded for farmers was a 50% satisfaction.

4.1.13 Influence of Co-production on Farmers Confidence and Forecast Information Sharing

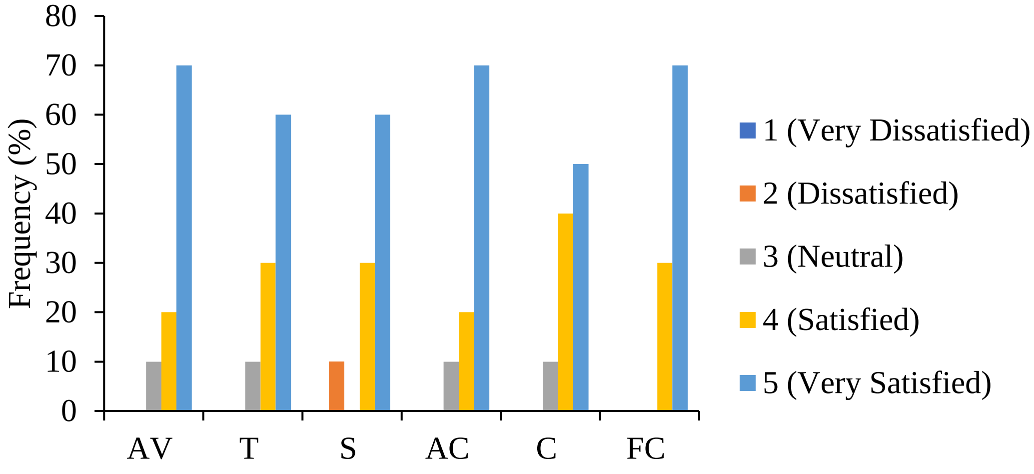
The farmers expressed very high confidence in the FSApp to provide them with relatively accurate weather forecast information. Community members who did not participate in the training equally used the weather information from the FSApp. According to the farmers who partook in the training, the non-participants sourced forecast information from them on daily basis, calling the group "the rain-maker people" and they did not hesitate to share the forecast information with others.

The farmers brought to our notice that the use of weather information from the FSApp went beyond the borders of the community and that is to say that, individuals from other communities also consulted them for weather information after encountering the FSApp.

The women also claimed that the relatively accurate predictions from the FSApp have built their confidence in the forecast provided by the FSApp and had encouraged them to share forecast information with other women on several occasions.

4.1.14 Availability, Timeliness, Credibility, Usability and Flexibility of the FSApp

Forecast was always available to farmers at all times through the FSApp. The information provided by the FSApp was clear and also on time, hence the forecast information was ready for use at all times. The farmers also mentioned that any time the scientific forecast section shows a probability of 81% or more, they are always sure that the rains will come and this has not failed them. Forecast was always available, except some few times that farmers didn't have access to the scientific forecast due to network unavailability.



AV - Availability; **T** - Timeliness;
S - Specificity; **AC** - Actionable;
C - Credibility; **FC** - Flexibility in Communication

Figure 4.10: Rating of Performance of the FSApp

(Source: Field survey, 2020)

Fig. 4.10 shows a very high rating for the various categories of performance viz; availability, timeliness, specificity, actionability, Credibility, and flexibility in communication with a corresponding majority of 70%, 60%, 60%, 70%, 50% and 70%, respectively. All six (6) categories recorded 5 as its highest score on the Likert scale, signifying a very high level of performance.

4.1.15 Major Behavioural Changes after Training

The livelihood of farmers in the Nakpanzoo community solely depends on farming and no risk, disaster or uncertainty can change farmers minds about doing agriculture. According to community members, farming is the only option they have. Based on the experiences of farmers, they believe that the rains will be coming earlier than usual next rainy season, hence they have decided to sow earlier next farming season. Also, the time that farmers usually go to the farm for fertilizer and chemical application had changed due to information received from the FSApp about the rains. Farmers explained that when chemicals and fertilizer are applied and it rains right away it will wash all the chemicals away hence, they normally delay application if the FSApp is telling them that there will be rains. Before going to the farm every morning, farmers consult the FSApp and there have been several occasions where they did not visit their farms to carry out the day’s activities due to the information received from the FSApp. The fact that farmers have to input their forecast every day encouraged them to access forecast information frequently.

Farmers in the Nakpanzoo community specifically actively use both traditional and scientific forecast for their daily weather-related decisions. Farmers mentioned that the moment all the members of the climate group give their responses on the status of the rain on a particular day, the majority of responses were compared to the scientific forecast before concluding the rains. Locally, farmers can only predict droughts of short duration that last for a week or less. Predictions over longer periods are not very accurate and so is the 7- and 14-days scientific forecast section of the FSApp. From farmers observations, predictions over longer periods are not as reliable as daily predictions.

Table 4.1: Changes Made Based on Forecasts Information from the FSApp: Men

Decisions points	**Yes/No/NA**	**Examples**
Changed of acreage cultivated	**NA**	It is not always dependent on rainfall, but also ability to buy inputs
Change of crop variety	**NO**	The farmers grow early maturing varieties and will continue to grow it. Varieties AGRA and Jasmine (3 months maturity period) are prefered
Change of planting date	**Yes**	The Farmers mentioned that their experience with the FSApp has revealed the credibility and reliability of the FSApp, therefore depending on the information that will be received from the FSApp farmers will decide either to start the season early or late
Change date of weed control	**Yes**	It was very common among farmers to change spraying days because the FSApp indicated a high chance of a rain.
Change decision for buying inputs	**NA**	Farmers think that buying of inputs is a complex matter and goes beyond access to forecast information.

(Source: Field Survey, 2021)

Table 4.2: Changes Made by Women

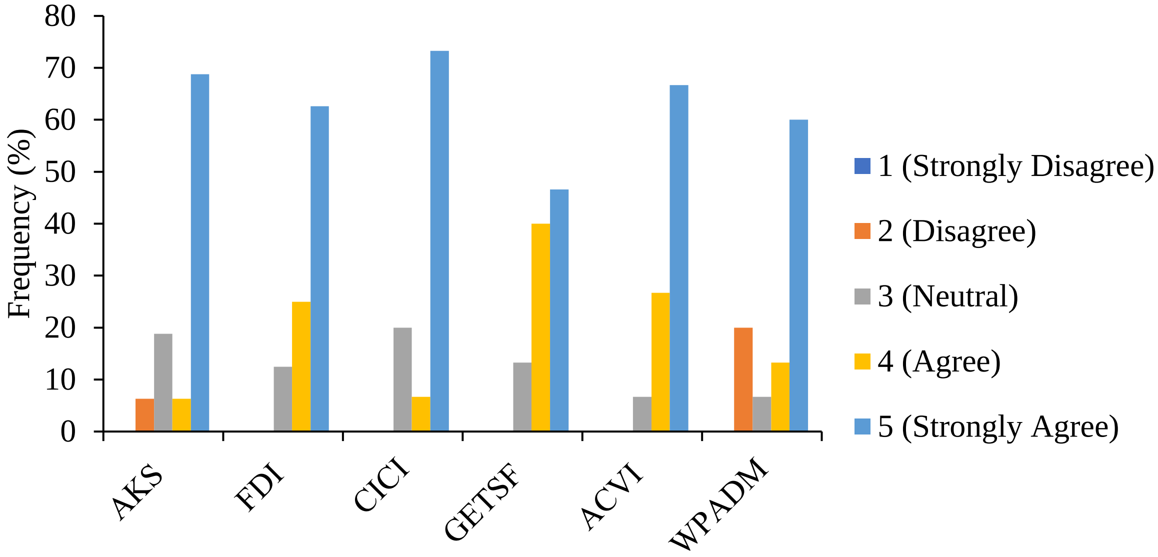
Decisions points	**Yes/No/NA**	**Reasons**
Changed of acreage cultivated	**Yes**	The women claim to be more certain about issues of when the rains will be coming and they think they will be increasing their farm sizes next season. Also, Mrs Bintu made mention that she was not able to farm this year and now that she has undergone a training to have access to a very reliable source of rainfall information, she hopes to farm next season.
Change of crop variety	**NA**	Women farmers always use the early maturing varieties (AGRA variety)
Change of planting date	**Yes**	They plan to cultivate earlier next season, but this will also depend on the first rains.
Change decision for buying inputs	**NA**	The decision to do this depends on many other factors, not just rainfall.

(Source: Field survey, 2020)

4.1.16 Key Impacts of Climate Services Co-Production on Livelihood Resources of Small-scale Farmers

4.1.16.1 Human Capital Development

Farmers are skilled at interpreting scientific forecast probabilities and farmers in the Nakpanzoo community for example, are capable of translating scientific forecast probabilities accurately to compare it to the local forecast and give reliable results and since they have not recorded so many misses, they believe they are doing the right thing. All the women in the climate group input their predictions into the FSApp and the final decision for the day includes their views, hence the women are always involved in the daily forecast and decisions for everyday activities. Both men and women indicated that anytime the scientific forecast section is 81% or more, they are sure to expect a rain. The women in particular expressed a high increment in the alertness of their surroundings. (Fig. 4.11).

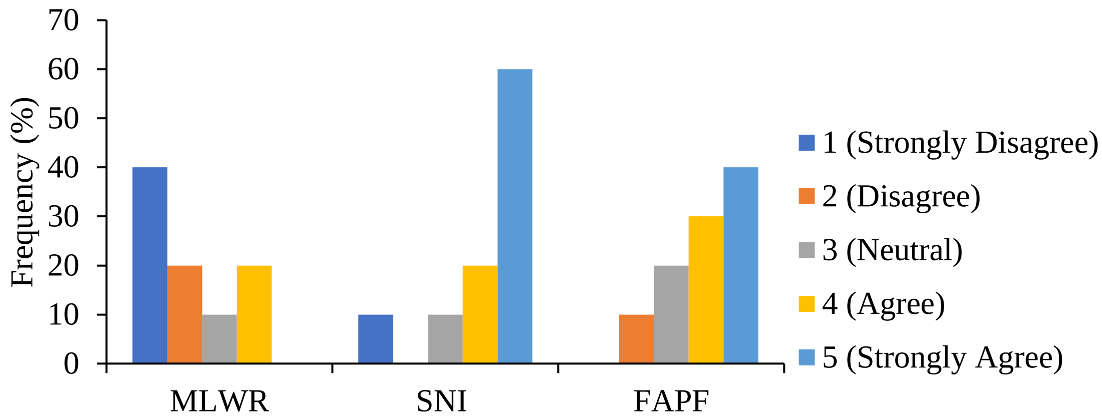


AKS - I have acquired new knowledge and skills
FDI - I am able to take farming decisions independently
CICI - I have improved my capacity for interpreting climate information
GETSF - Gained experience in using traditional and scientific forecasts
ACVI - My awareness on climate variability has increased
WPADM - Women participation and voice in agricultural decision-making has increased

Figure 4.11: Ratings of Human Capital Development

(Source: Field survey, 2020)

4.1.16.2 Natural and Social Capital Development



MLWR - Management of land and water resources has improved
SNI - After participation in the training my social network has increased
FAPF - Can provide forecasts assistance to peer farmers after training

Figure 4.12: Ratings of Natural and Social Capital Development

(Source: Field survey, 2020)

Farmers seemed to be very positive about using information that they are currently receiving from the FSApp to manage their rice farms and also prepare for the next season. Farmers claimed that their fields were flooded before the start of the training on the FSApp, hence nothing much could be done about land preparations after the training (Fig. 4.12). In addition, according to the women, the issue of land management has to do more with finance than the weather. Men may have access to use the tractor services before the women also have access to it, due to women's limited ability to pay.

After meeting to input forecast in the morning, most of the farmers have to relay the forecast information to other farmers both in the community and outside the community. The farmers acknowledged the fact that the use of the FSApp has increased the rate at which they interacted with each other. The social network of farmers has increased, as shown in Fig. 4.12. Most

(70%) trained farmers were highly capable of providing forecast assistant to peers, out of the 70%, 40% recorded the highest with a Likert score of 5, followed by another 30% recording 4 on the Likert scale. About 10% of the farmers could not share forecast with other farmers and they rated 2 on the Likert scale.

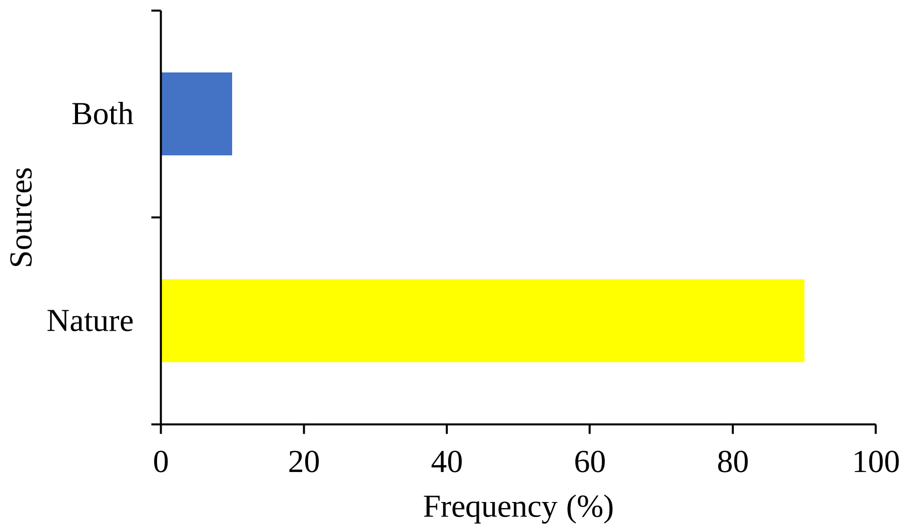


Figure 4.13: Rating of Sources of Climate Variability

(Source: Field survey, 2020)

Fig. 4.13 shows that 90% of the farmer's associated climate variability with nature, stating that “God is responsible for everything concerning the rains”. 10% of the others think that both nature and the activities of men are responsible for climate variability.

4.1.17 Awareness of Climate Variability and Confidence of Farmers in Handling Weather Related Activities

Farmers seem sure about food availability since they have a way of managing the risks associated with rainfed agriculture. They also mentioned that sometimes if the fields are already flooded, nothing can be done even if the weather can be predicted afterwards. When the season delays sometimes (when the rains come later than expected) farmers end up diverting the money that was intended for purchasing inputs into other activities and they are not able to farm as much land as planned. Farmers trust the current information from the FSApp and are willing to continue using it from season to season. But if the consistency of predictions should change, farmers will divert to other sources. Farmers are willing to pay for climate services provided the information is reliable as observed with the FSApp.

4.1.18 Yapalsi Community

4.1.19 Co-production and Behavioural Change

The co-production made the weather forecast very interesting since each farmer had to observe his/her environment in other to enter a prediction. Farmers do their best to input predictions and also discuss the weather every morning. The FSApp was available to farmers to access weather information at will hence farmers felt very confident using the FSApp. Most community members, including those who did not participate in the training, expressed their appreciation for how useful the FSApp had been to them. Most farmers adopted the attitude of consulting the FSApp any time they wanted to go to the farm. The women, in particular, used the FSApp for making other decisions aside that related to agriculture. e.g. domestic chores, going to the market and community meetings.

4.1.20 Usefulness of Forecast in Decision Making in Agriculture and Other Sectors

The farmers in the Yapalsi community consulted the FSApp to carry out any form of agricultural activity. Most of the male farmers claim to use the forecast information from the FSApp only for agricultural activities. Few claimed to engage in other economic activities outside the community and they relied on the FSApp for weather information to check the status of the rains before riding out of the community. The success of most farm activities (fertilizer, spraying of chemicals, weeding) depends on the farmers ability to forecast the weather. Farmers confirmed that forecast information was available at the required time. Farmers used forecast information to plan their agricultural activities including the following; when to purchase inputs, land preparation, sowing, application of fertilizer and weedicides and organisation of labour to work on the farms. After farmers had discovered the accuracy of the FSApp, they always consulted the FSApp before going to the farm to carry out any activities.

For example; Mr. Ibrahim Adam, a rice farmer in the Yapalsi valley who was not a member of the climate group made mention that, he did spraying three times this season and for each spraying, he consulted the FSApp before going to spray and this was to ensure that the rains were not going to come. He explained that after spraying the chemicals have to take at least 6 hours before the rains, else if the rains should come any sooner than that it was going to wash away the chemicals, causing financial losses. He also mentioned that there were days he had to postpone the spraying because the predictions said it was going to rain that day and truly it rained, so for him, he trusts in the FSApp and relies on it completely for his spraying activities. The FSApp was not only used by rice farmers but the entire community, which included groundnut farmers and maize farmers. These farmers also expressed great satisfaction with the FSApp. Groundnut and maize were harvested earlier before the end of the rainy season hence during the harvest most of the community members consulted the FSApp before going for the harvest. In the community, women were responsible for the post-harvest handling of groundnuts. Before the women dry the groundnut under the sun, they also needed to be sure of the cessation of the rains.

4.1.21 Platforms Currently Being Used for Forecasts Information

Farmers realized the accuracy level of the FSApp after they were trained to use it. Farmers started using the FSApp gradually, until they have completely adopted it, favouring it over the radio and information from other platforms, such as Vodafone. Farmers have realized that information from the FSApp is reliable and they mentioned the FSApp to be the first source of their weather information. A few of the farmers mentioned using the radio and other platforms such as Vodafone (network provider) for comparison. (Fig. 4.14)

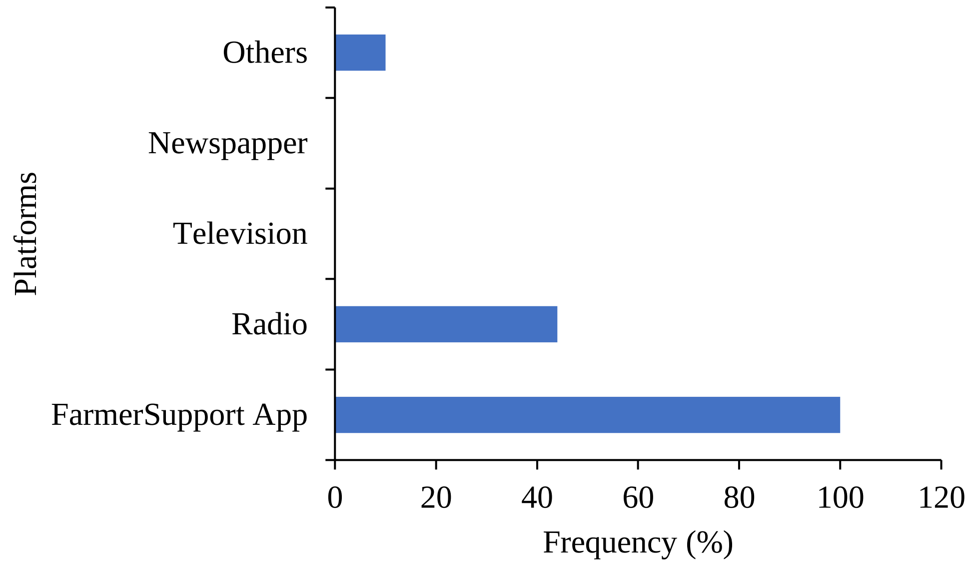


Figure 4.14: Platform Preferences After the FSApp Implementation

(Source: Field survey,2020)

4.1.22 Suitability of the FSApp Relative to the Previous Platforms Used

Relative to the other platforms, the farmers expressed a very high level of satisfaction using the FSApp. The farmers control the FSApp, they decide when to visit it, they don't need to wait on anyone to bring them information hence the farmers find the up to be more suitable and convenient to them. The women particularly said that all the predictions that they have utilized from the FSApp so far were accurate.

After farmers had used the FSApp and experienced a few successes, it boosted their confidence and they felt very secured about their plants on the field. Farmers also found the interpretation of weather information from the FSApp to be easy and quick relative to the previous platforms used. It can be seen in Fig. 4.15 that the majority of the farmers gave the highest score for both happiness and suitability of the FSApp and no score was given below 3 on the specified Likert scale.

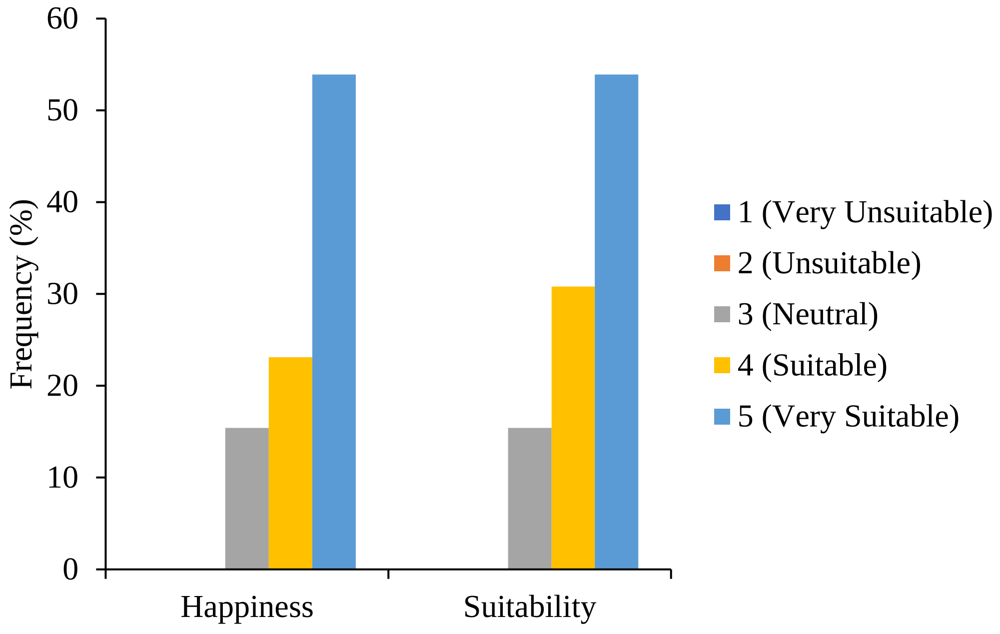


Figure 4.15: Rating of Happiness and Suitability of the FSApp in Farmers' View

(Source: Field survey,2020)

4.1.23 Influence of Co-production on Forecast Information Sharing

Farmers who partook in the training found the FSApp to be very reliable and therefore had no problem sharing weather information with other farmers in the community. Farmers explained that the other farmers with whom they shared weather information would have seized coming to them if the information was not helpful to them but then they always came for weather information. when there are dry spells, farmers seek to know the status of the rain in the next 7-14 days, hence farmers rely more on the 14-Days forecast during the period of dry spells. Farmers share weather information with other neighbouring communities.

During the dry spell (in August), most farmers were frustrated and were looking for sources of weather information. A group of farmers from the community of Sankpium Bogu decided to travel to seek information about the weather in the Yapalsi community. A member of the climate group (Mr. Isahaku Suale) consulted the FSApp and told the farmers that there will be no rains for the next 7 days. After several days without rains, the farmers called to thank

Mr. Isahaku Suale for saving them the stress and cost of further travelling and till date they call Mr Isahaku Suale for weather information.

4.1.24 Availability, Timeliness, Credibility, Usability and Flexibility of the FSApp

The forecast was available. Farmers always had access to weather information at any point in time that they needed it, provided there was a network. Due to the frequent successes in predicting the weather accurately, farmers developed trust in the FSApp. The farmers also trust each other not to communicate the wrong information about the weather.

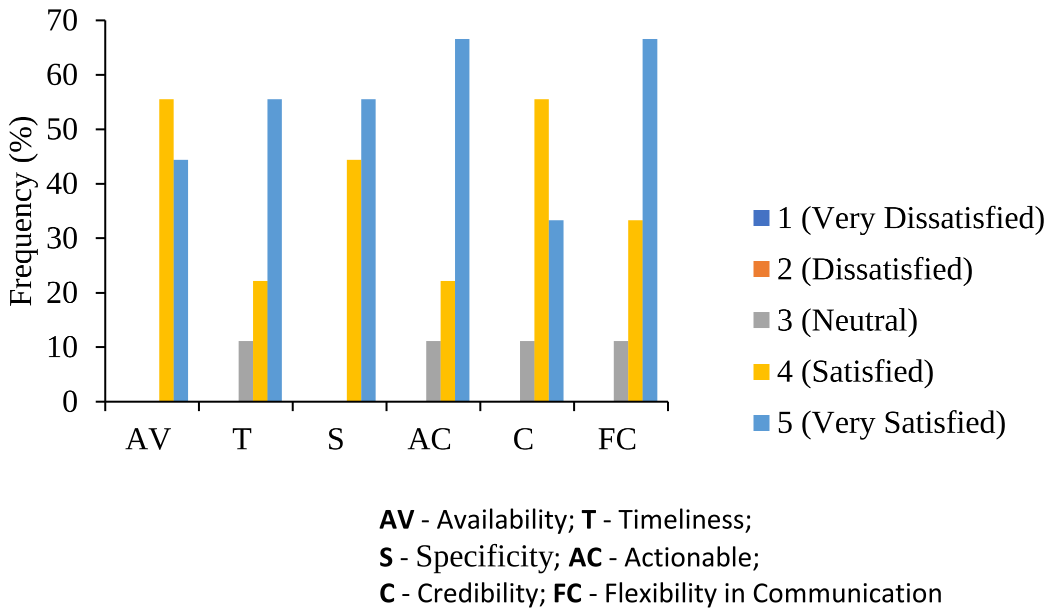


Figure 4.16: Rating of Performance of the FSApp

(Source: Field survey,2020)

Fig. 4.16 shows the rating of the various indicators of the performance of the FSApp on a Likert scale of 1-5. The least score recorded on the Likert scale was 3 for four (4) indicators (timeliness, actionability, credibility and flexibility) and 4 for two (2) indicators -(Availability and Specificity), respectively, depicting a high level of performance of the various indicators. The majority ratings of the various indicators are as follows: 55.5% scored availability 4 on the Likert scale, 55.5% scored timeliness 5, 55.5% scored specificity 5, 66.6% scored actionability 5, 55.5% scored credibility 4 and 66.6% scored 5 for flexibility.

4.1.25 Awareness of Climate Variability and Confidence of Farmers in Handling Weather-Related Activities

About 80% of the farmers associated the weather and its variability to nature. The farmers said they believe that everything about the weather and climate is in the hands of God. The remaining 20%, which were predominantly women, believed that bush burning by humans also contributed to climate variability. Most farmers admitted that they believe that climate change threatens their lives to a significant extent. (Fig. 4.17).

The level of confidence farmers feel in handling weather dependant activities has improved. Having access to reliable weather information can save a lot of money in terms of labour fertilizer purchase and application, spraying and land preparation. According to the participants, farming is the basic source of livelihood in the community, therefore they will continue to farm. Based on the accuracy level, co-production and simple nature of the FSApp farmers seem to be very sure about the continuous use of the FSApp.

Farmers are ready to pay for climate services provided it will be easy to understand and also provide them with reliable weather information.

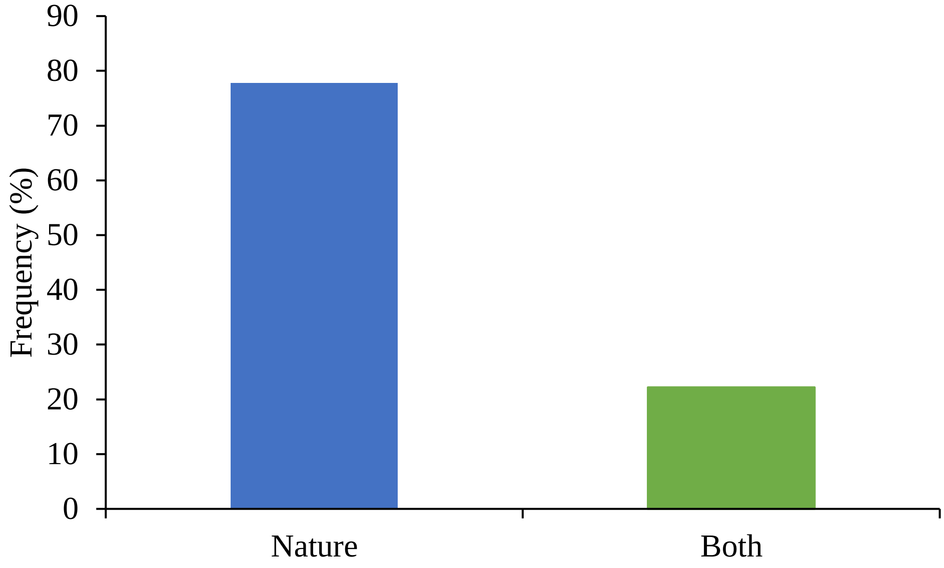


Figure 4.17: Sources of Climate Variability

(Source: Field survey,2020)

4.1.26 Major Behavioural Changes After Training

Farmers claim to access forecast information more frequently after training relative to the other platforms even though they still check the other platforms to make comparisons. Farmers are now used to forecasting before leaving home. Farmer's reliability on the FSApp is relatively higher than the previous platforms but even when the FSApp was not there the farmers used forecast information from other platforms like radio and service providers (Vodafone) and as well as the rainmaker. Farmers rely on both scientific and local forecast but the men claim to use the scientific forecast more (daily, weekly and 2-weeks forecast). The farmers also mentioned that their confidence level increased if both scientific and the majority responses from the traditional forecast are in agreement. The farmers expressed a high level of confidence in forecast information received from the FSApp.

Table 4.3: Changes Made Based on Forecasts Information from the FSApp: Men

Decision points	Yes/No/NA	Example
Changed of acreage cultivated	**yes**	**Mr. Amadu Musa** is planning to increase his land size from 2-5 acres next season. **Mr. Lukeman Adam** from 2 acres to 4 acres next season. **Mr. Adam Abdulai** said that parts of his land were flooded hence he cultivated just 1 acre this season and he's planning to increase it to 7 acres next season.
Change of crop variety	**No**	Agra is an early maturing variety and it also yields very well. Farmers are not planning to change it for any reason.
Change of planting date	**NA**	This can only be known when the next season starts. But for this season, there was no change in planting dates.
Change date of weeding	**Yes**	There have been several occasions where farmers had to consult the FSApp before organising labour for weeding.
Change decision for buying inputs	**Yes**	Farmers don't buy inputs when they are not receiving rains. farmers only buy inputs (e.g. fertilizer) if farmers are aware of the coming of the rains so as to prepare for its application.
Change date of fertilizer application	**Yes**	When there is drought, farmers claim they don't apply fertilizer. In August there was a long spell of dryness and with the help of the FSApp the farmers were able to have an idea using the 14-day scientific prediction.
Change date of pesticide application	**Yes**	There were several instances where farmers had to postponed spraying activities

(Source: Field Survey, 2021)

4.1.27 Changes Made Based on Forecasts Information from the FSApp: Women

The women in the Yapalsi community agreed that they were going to make changes in the activities listed in Table 4.4. They said that changing the decisions about farming activities depends on several parameters other than the current weather forecast, such as availability of resources, the onset of the rains the next season and availability and cost of inputs. Almost all the farmers in the Yapalsi valley use the AGRA rice variety which is claimed to be early maturing by farmers.

Table 4.4: Changes Made by Women

Decision points	Yes/No/NA	Example
Changed of acreage cultivated	Yes	This depends on finance and most women in the Yapalsi community may not be able to afford an expansion of the land area. But with financial support, the women are willing to expand their lands.
Change of crop variety	**NA**	The women always use the AGRA variety which matures within three (3) months
Change of planting date	Yes	Depending on the onset of the rains, women farmers plan to change sowing dates the next farming season.
Change date of weeding	Yes	Some of the women farmers had to change weeding dates. Mrs. Shaibu reported that there was a day she planned to go to the farm to weed and the forecast from the FSApp indicated that there were going to be rains, but she went to the farm anyway. Just about 30 minutes after she left for the farm, it rained heavily and she came back to the house postponing the weeding to another day.
Change decision for buying inputs	Yes	Decisions for buying inputs were changed most during the dry spells in August since farmers had to wait for the rains before planning to buy inputs (especially fertilizer).
Change date of fertilizer application	Yes	When there is drought, farmers claim they don't apply fertilizer. In August there was a long spell of dryness and with the help of the FSApp, the farmers were able to have an idea using the 14-day scientific forecast.

(Source: Field survey, 2020)

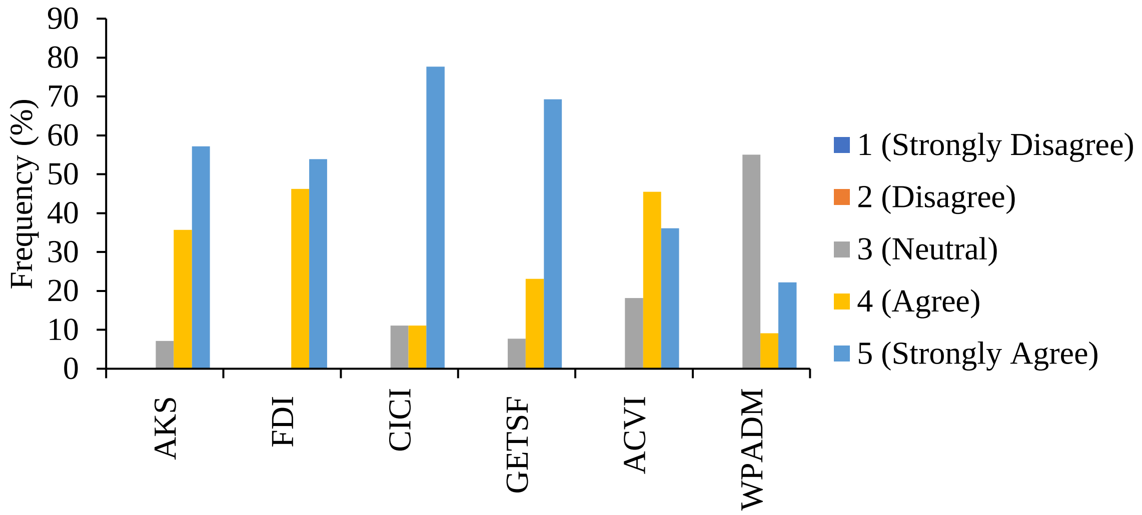
4.1.28 Key Impacts of Climate Services Co-Production on Livelihood Resources of Small-scale Farmers

4.1.28.1 Human Capital Development

Farmers in the community did not have much knowledge about the weather and therefore relied on the radio for weather forecast information. But after the introduction of the FSApp farmers can understand weather phenomena better and what it means when the scientific forecast shows a rainfall probability of 90%. The farmers have also learnt to handle smartphones quite well. It is shown in Fig. 4.18 that, all analysed categories reveal an appreciable level of performance, with the least Likert scale value being 3.

Women were given the chance to participate fully in daily forecast entries and most of them consulted the FSApp before carrying out agricultural activities. In the Yapalsi community, the voice of women is still not heard sufficiently, but women are hoping that the use of the FSApp will improve their inputs on issues relating to agriculture in the future (Fig. 4.18).

During the earlier stages of the training, most community members had incurred some losses by not adhering to the forecast from the FSApp. This had gone a long way to increase the trust farmers have for the FSApp.



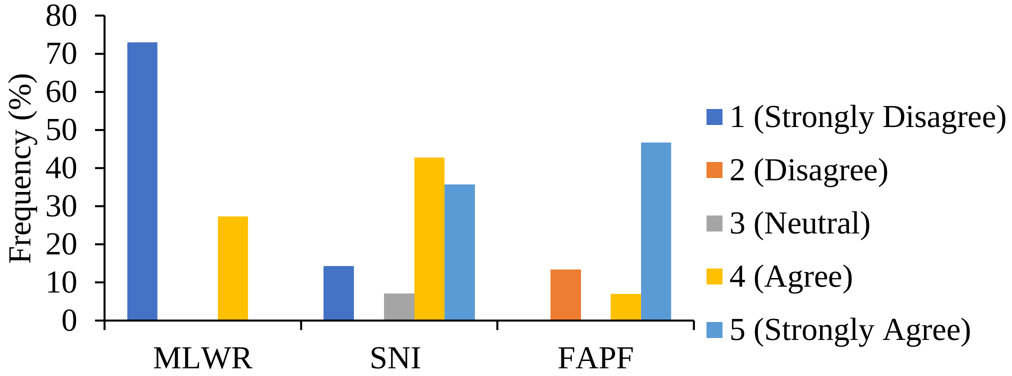
AKS - I have acquired new knowledge and skills
FDI - I am able to take farming decisions independently
CICI - I have improved my capacity for interpreting climate information
GETSF - Gained experience in using traditional and scientific forecasts
ACVI - My awareness on climate variability has increased
WPADM - Women participation and voice in agricultural decision-making has increased

Figure 4.18: Ratings of Human Capital Development

(Source: Field survey, 2020)

4.1.28.2 Natural and Social Capacity

Land preparation for farmers in studied communities depended more on capital available and not much on the weather. Since farmers already started land preparation before the training, they hoped to improve on land management next season. The women usually shared information of the forecast with their colleagues who were mostly traders and from neighbouring communities. Fig. 4.19 shows that 73% of the farmers did not use forecast information at all in land preparation and water management, 27% however used this information to manage land and water. Majority of the farmers agreed that their social network had increased much due to the use of the FSApp but yet 14% did not see this improvement. 47% of the farmers can provide excellent forecast assistance to peer farmers whilst 20% can provide assistance on a moderate level.



MLWR - Management of land and water resources has improved
SNI - After participation in the training my social network has increased
FAPF - Can provide forecasts assistance to peer farmers after training

Figure 4.19: Ratings of Natural and Social Capital Development

(Source: Field survey, 2020)

4.2 Discussions

4.2.1 Analysis of Skill-score

The focus of the analysis was on rainfall events since this is the main concern of small-scale farmers and more specifically, rice farmers whose farming activities rely on rainfall. The results from the analysis revealed the skill of the LFK to be 0.50. This high skill score of LFK indicates that the use of indigenous ecological indicators has highly significant skills at predicting rainfall events, similar to the score of LFK obtained from the research carried out by Gbangou *et al*., 2020 at Ada, in Southern Ghana. This score also agrees with the findings from many researchers, including Gbangou *et al*., 2020; Codjoe *et al*., 2014, which reported that local forecast knowledge is very important in predicting the weather for local people and hence, a vital component of the forecast information available to farmers for their farming decisions.

The scientific forecast data from meteoblue also portrayed a very valuable skill score when analysed against the rain gauge data from the two (2) project communities (Fig. 4.2). The SFK skill score was higher than that of the LFK skill score (Fig. 4.5), with a difference of 0.11 which was significant in terms of the score. This shows that the scientific forecast predicted close to the ground situation better, compared to the LFK which agrees with Naab *et al*., 2019 who mentioned that local forecast alone will no longer be sufficient for small scale farmers since climate change is resulting in the loss of fauna (Birds, Frogs, Butterflies, Ants) and flora (Trees, Herbs, Grasses) upon which local predictions are based on.

However, Fig. 4.6 shows that 85.9% of all predictions provided by farmers were based on celestial bodies and just 9% based on environmental observations of flora and fauna in our study area.

The integration of scientific and local forecast under integration scenario one yielded a slightly higher skill score, compared to both scientific forecast and local forecast skill scores, respectively (Fig. 4.5). Higher skills observed for IS-one shows that an integration between LFK and SFK is better than any of the individual skills alone, even though the difference between the H-K score of IS-one and SFK is not very significant (0.01) as compared to the difference between LFK and IS-one (0.12) which is quite significant. It also shows that using SFK alone for predictions works better than LFK alone, since the accuracy levels of the LFK is relatively low.

4.2.2 Indigenous Ecological Indicators

The indigenous ecological indicators represent a very vital component of the LFK forecast. The indigenous ecological indicators were the basis of LFK predictions. The trend of the frequency of utilization of the indicators indicated that most of the farmers based their daily forecast inputs more on observations of celestial bodies for the ninety-two (92) day rainy period as seen in Fig. 4.6. A total sum of 85.9% of all forecasts were based on observation of celestial bodies, whilst only 9% were based on observations of biota in the farmer's surroundings. The relatively low skills of the LFK skill score could be associated with the condition that transferring a set of indigenous ecological indicators from one locality to the other the indicators may not have the same predicting power because a different region/locality may have indicators denoting different weather patterns with different performances in predicting rainfall occurrence. (Gbangou *et al*., 2021).

Also, it will be a valid inference to associate the relatively low LFK in forecasting the weather to diminishing biota in the farmer's environment. This diminishing biota could be associated to population increase and climate change which also puts the sustainability of LFK at risk.

4.2.3 Platforms from which Rice Farmers Obtain Forecast Information

Aside from farmers local way of forecasting the weather, rice farmers in these valleys receive agricultural information (weather forecast information) from radio stations, agricultural extension agents, agricultural organizations/institutions, mobile phones, television and peers. Since these farmers rely on the rains for their crops, they need this information to plan and to reduce the uncertainties that come with rainfed agriculture.

4.2.3.1 Platforms that were Used Before the Implementation of the FSApp

Results from the interview showed that farmers currently source agricultural information from radio stations, agricultural extension agents, agricultural organizations/institutions, peers, television and mobile phones. The majority of farmers received forecast information from radio stations and agricultural extension agents, recording on the average 35.1% and 27.8%, respectively, for the two (2) communities (Fig. 4.14). Very few farmers received forecast information from agricultural organisations (MiDA, WASCAL, ADVANS) and peers.

4.2.3.2 Adoption of the FSApp Over Other Forecasting Platforms

Comparing the results from Figs. 4.14 and 4.8 to 4.7. It was revealed that before the FSApp was introduced to farmers in the two valleys, farmers obtained forecast information mainly from the radio (Fig. 4.7). After the implementation, all of the farmers involved in the study rely on the FSApp for their daily forecast needs, with just 40% using the radio in addition to the FSApp showing that 60% of the farmers had adopted the FSApp completely superseding the other platforms in both valleys. This adoption rate could be associated with co-production, as explained in section 4.2.4.

4.2.4 Effect of Co-production on the Adoption of the FSApp

Co-production is a participatory approach where knowledge generation is based on the interaction between science and society. This approach is based on the principle of stakeholder participation and also on the knowledge that solutions and plans developed by tackling issues from the grass-root are more sustainable in all aspects of living. Participation is expected to result in the incorporation of the interests and expectations of all stakeholders to the project. (Urquhart *et al*., 2014; Bremer and Meisch, 2017).

The implementation of the FSApp begun with a baseline study in order to incorporate the views of the farmers right from the beginning of the project so as to achieve the aims of the project. Co-production in the first place encouraged farmers in both communities to be responsible for the FSApp. Farmers knew what the FSApp was about, they owned it and were proud about visiting the FSApp every morning to input their forecast. As seen in section 4.2.3, farmers were receiving forecast information from different sources before the introduction of the FSApp but just within a single season results show that farmers have adopted the FSApp over the previous platforms. This abrupt adoption can be attributed to co-production. (Nyadzi *et al*, 2020).

The FGDs revealed that before the implementation of the FSApp, few farmers paid much attention to the environment to make predictions of the weather but since the FSApp required for them to input their forecast as well farmers seem to pay much more attention to their environment. Also, Co-production made it easier for farmers to share knowledge with peers due to their trust in the FSApp (Fig. 4.10 and 4.16)

4.2.5 Knowledge of Farmers on Weather After Implementation of the FSApp

Farmers knowledge of the weather (mainly SFK) before the implementation of the FSApp was almost negligible. Farmers had to rely on sources like the radio for weather forecast information. Weather information from the radio was not localized and did not relay enough information to the farmer about the weather for adequate planning and management of their farms.

The results from the evaluation of the FSApp revealed that farmers capacity in understanding and interpreting the weather had improved after introducing the farmers to the FSApp. Figs. 4.11 and 4.18 show that farmers knowledge of climate phenomena had increased significantly.

This has encouraged most farmers to share knowledge with peers and also use forecast information to make some changes in their farming activities. (See Table 4.1, 4.2, 4.3 and 4.4). Farmers inability to utilize forecast information for managing land and water resources on their farms was attributed to the late implementation of the FSApp. Farmers' fields were flooded before the implementation of the FSApp hence nothing much was done about land preparations and water management after implementation (Fig. 4.12). Additionally, few farmers have enough knowledge about climate variability. As shown in Fig.s 4.13 and 4.17, where most of the farmers attributed climate variability to nature only. However, farmers are very much aware of the consequences of climate variability on their agricultural activities.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study accessed the skills of the FSApp (SFK and LFK) in predicting the weather as compared to the ground situation and also evaluated the overall outcome of the implementation of the FSApp on farming activities in selected communities. For the skills analysis, integration Scenario One recorded the highest skill score which was not significantly different from the skill of the scientific forecast knowledge (meteoblue). The local forecast knowledge recorded the least but significant skill score, relative to SFK and IS-one, respectively. The higher H-K skill score observed for IS-one is an indication of the importance of both LFK and SFK for making a more reliable forecast, but it seems local forecast cannot stand alone for making decisions relative to scientific forecast which will still perform better than LFK for forecast predictions. The majority of indicators upon which LFK was based throughout the 92 days consisted more of observations of celestial bodies, meaning farmers observed celestial bodies more than their surrounding biota for forecasting.

Results of the final evaluation revealed that co-production was a great tool in promoting adoption. In the project, co-production led to building the trust of farmers in the forecast from the beginning before discovering the skillfulness of the FSApp in predicting the rains. The very high adoption rate observed was as a result of both co-production and the relatively accurate predictions given by the FSApp. Also, the FSApp had a very simple interface which facilitated quick understanding and adoption. By using weather information from the FSApp, farmers were able to manage the numerous risks associated with rainfed agriculture and to change certain decisions on agronomic practices due to information received on the status of the rains. Farmers knowledge of climate phenomena had increased significantly, indicating that the training was successful. Farmers awareness level on climate variability is significantly high but most of them (male-dominated) are unaware of the cause of climate variability. Women demonstrated a higher knowledge of the causes of climate variability.

The trend of forecast observed where the skill of IS-one > SFK > LFK, correlates with the perception of farmers in the two (2) project communities about the reliability of the SFK section which is portrayed by farmers as the most used forecast section of the FSApp.

5.2 Recommendations

- Program should be written to merge scientific and local forecast so that a complete hybrid forecast will be displayed to ease the decision-making process for farmers (the experiment may be repeated to provide a more solid basis for developing the hybrid forecast section).
- Documentation of indicators for different ecological zones is needed since indicators may vary for different regions.
- Future experiments should be carried earlier i.e. at the onset of the rains.
- A more refined algorithm should be used to make the data storage on the server more precise.
- Finally, the FSApp should be made widely available to rainfed farming communities.

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APPENDICES

Appendix A: Training Manuals

The FSApp was a new product that did not come with an instruction manual. The development of the manual was a part of the research proceedings. To effectively train farmers and also for future use purposes, detailed manuals were prepared using more pictures, figures and illustrations to facilitate teaching and learning since people learn better by sight and in the case of our farmers might be the only possible way they can understand and better use the app.

1.1 Introduction of The FSApp

- Climate is one of the major determinants of agriculture and rural livelihoods.
- Efforts are been made to encourage mitigation of climate-related risk in agriculture, disaster risk reduction and water management.
- The FSApp is a tailor-made App specific to the Ghanaian context.
- The app was developed to be used as a basis of decision making in agriculture activities that rely on the climate.

In order to sustain agricultural productivity, the ability to Forecast the weather to an appreciable accuracy is very necessary for making the following decisions: **Land preparation, Sowing/transplanting, Fertilizer application, Pest control and harvesting.**

Land clearing

Sowing/Broadcasting

Fertilizer application

Pest control

Harvesting

- The added advantage is that the app predicts on the basis of both scientific and indigenous forecast which tremendously improves on its accuracy and reliability.
- The basis for the scientific predictions is based on forecast from meteo-blue.
- The app gives users the chance to input their own predictions based on the indigenous ecological indicators.
- The implementation of this app will aim to improve water management on the field and increase food security while achieving knowledge co-creation and sharing within the farming community.

1.2 App Installation

Requirements

- An android phone or tablet (performs better on larger screens of about 7 inches)
- Bandwidth 15 MB minimum required for downloads
- required installation space: 30 MB minimum
- Internet connection required for the daily operation of the app

Installation procedure

i. make sure your phone is charged (20% minimum) preferably fully charged

ii. Make sure you are connected to the internet

iii. Turn on the screen of your phone and tap on the "**google play store icon".** This will open the play store**.**

iv. On the search bar, type in **“farmersupport”** and search.

v. A list of apps will appear, look out for the one with the icon below and the name, **“FarmerSupport”.**

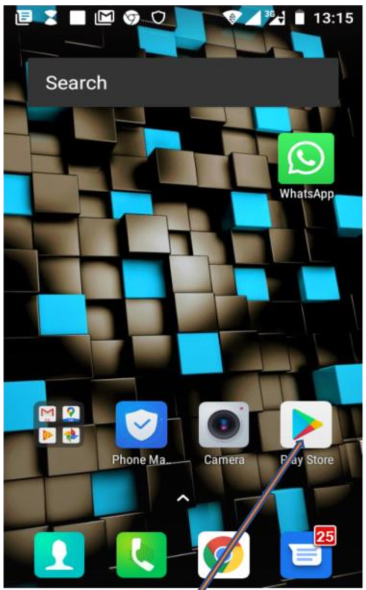
vi. Click on the icon to download the app after that tap on install on the downloads screen to install the app.

vii. After installation, you can close the app store

viii. You will find the app either on the home screen or your apps menu. Tap on the app to start it.

1.3 APP INSTALLATION (PICTORIAL Illustrations)

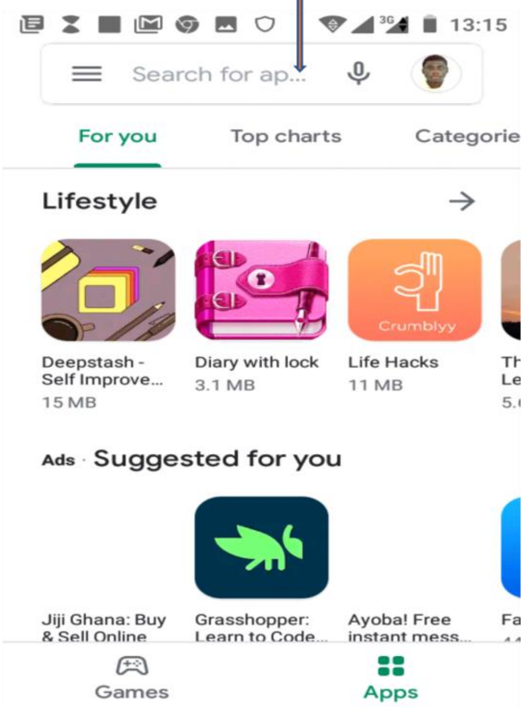
Step 1



From your phones menu tab on the play store this opens “step2”

Step 2

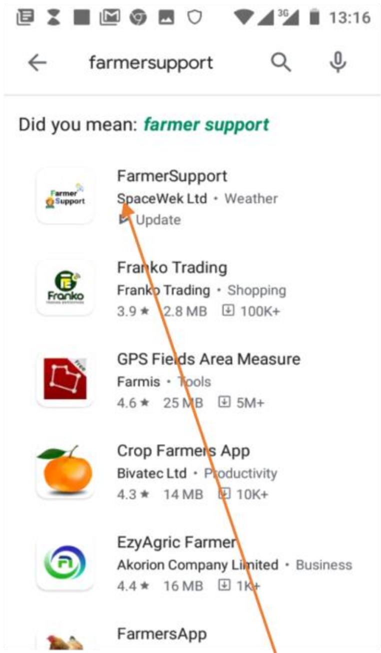
Type “farmersupport” into the search bar



Step 3

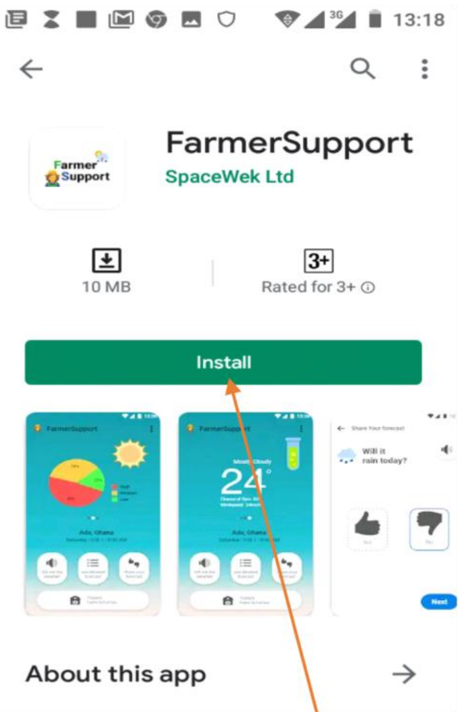
Tap on search after typing "farmersupport" this leads you to step 4

Step 4



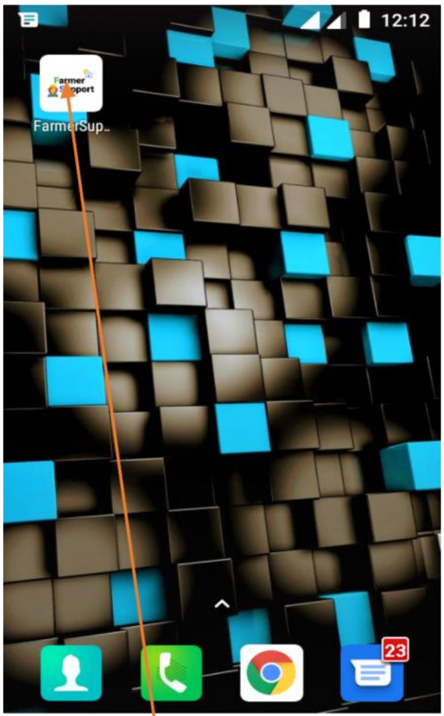
Tap on the FSApp and this opens step 5

Step 5



Tap on "install" to download and install the app

Step 6

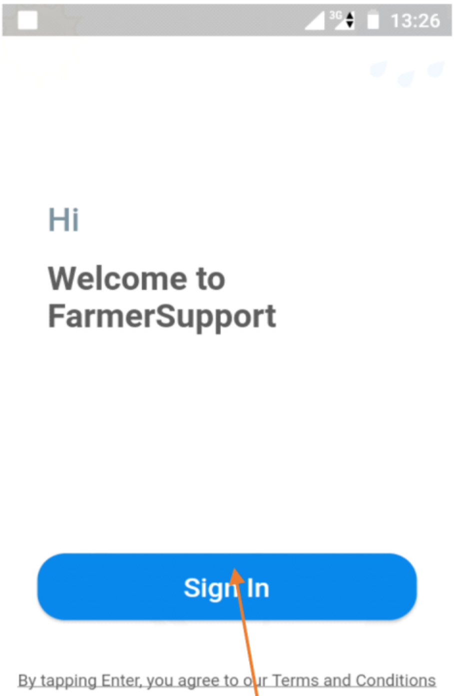


Tap on the icon to launch the app for the first time.

1.4 APP REGISTRATION (SIGN UP)

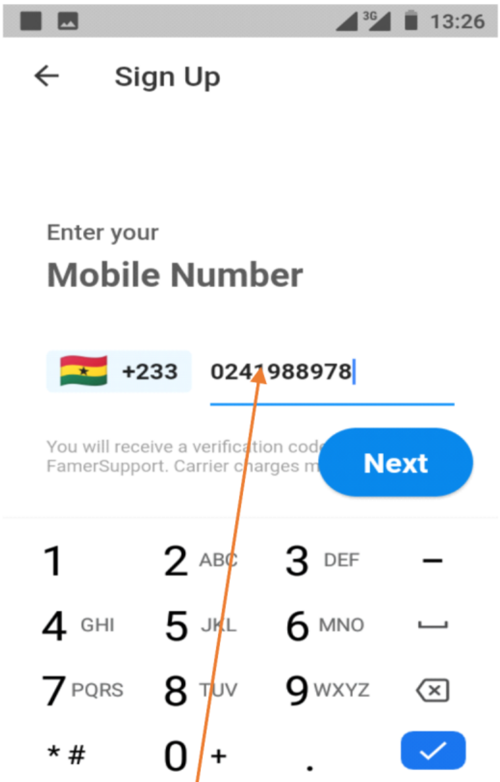
- Currently, the app can only receive a single sign up. Meaning multiple farmers cannot sign up onto the same app on the same phone.
- When the app starts for the first time, this is what you see

Step 1



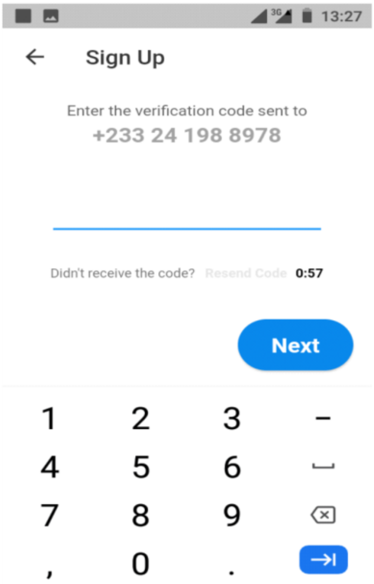
You will see this page, when you run the app for the first time. Tap on "sign in" to open the next step (step 2)

Step 2



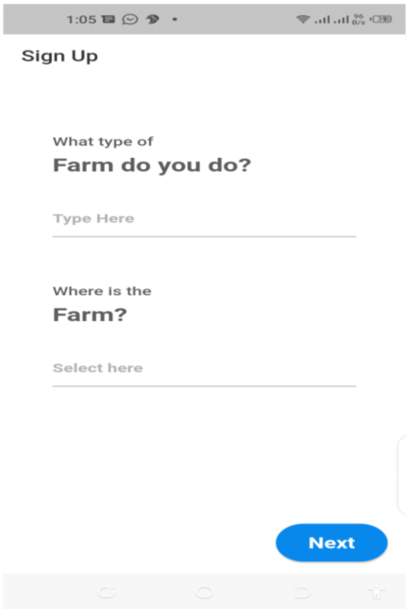
Dial your telephone number and click next to open step 3

Step 3



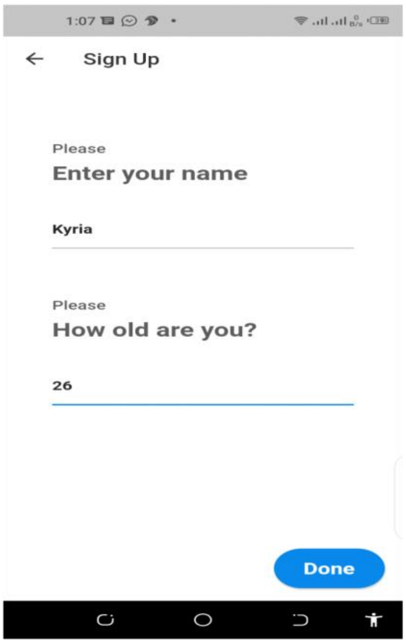
A code will be sent to verify your number. After dialing in the code tap next to open step 4

Step 4



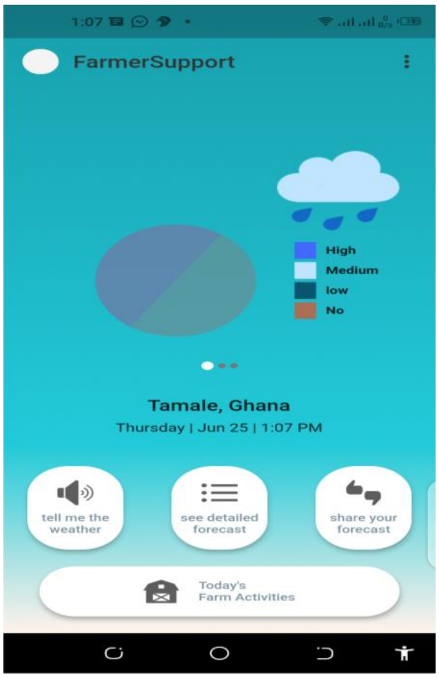
Fill in the required details and tap next to move onto step 5

Step 5



Fill in the required details and tap Done to complete the registration. If successful, you should see the FSApp home page as in step 6

Step 6



App home page

1.5 Multi-registration processes

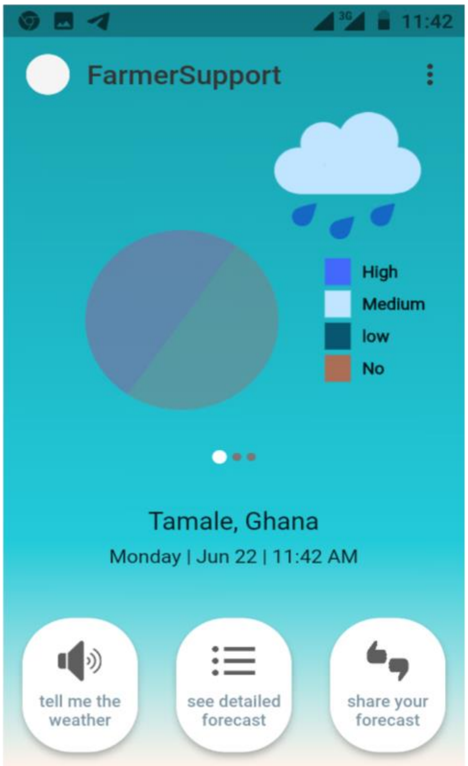
The multi-registration process is used to allow a group of people to utilize a single app installed on a single smartphone for daily monitoring and input of local forecast information into the FSApp. In other words, if the number of phones available is less than the number of users, the multi-registration procedure should be followed for each user to be able to utilize the app.

a) Follow the steps in section 1.4 to register a mobile number (farmer) on the app.
b) To register a second phone number(farmer), the first thing to do is to sign out from the app.
c) After signing out, the next step is to tap on sign in and input the second farmer's mobile phone number and proceed to tab on next.
d) After that, a 6-digit number will be sent through SMS to the farmer's phone, and this code will be entered into the app to register the farmer.
e) Next, the farmer would have to input the type of farm he does, his location, name and age to complete the registration process.
f) Steps **b - e** should be followed to register any number of people on the app on a single smartphone.
g) Once a farmer is registered, he/she does not need to go through all the steps the next time he/she wants to use the app all that the app will require is the phone number and the code that will be sent to the farmers phone to re-register the farmer to input his predictions the next time he/she tries to sign into the app.
h) This procedure has to be followed every day for farmers to input their predictions into the FSApp.

1.6 App Interface

Page 1

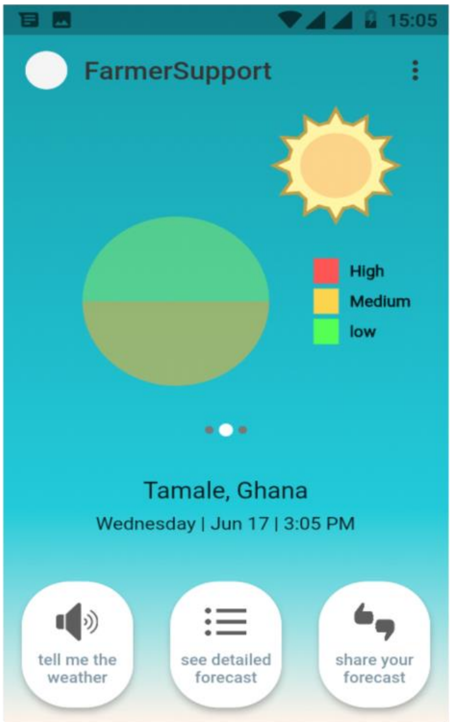
By sliding left, you move to the next page “page 2”



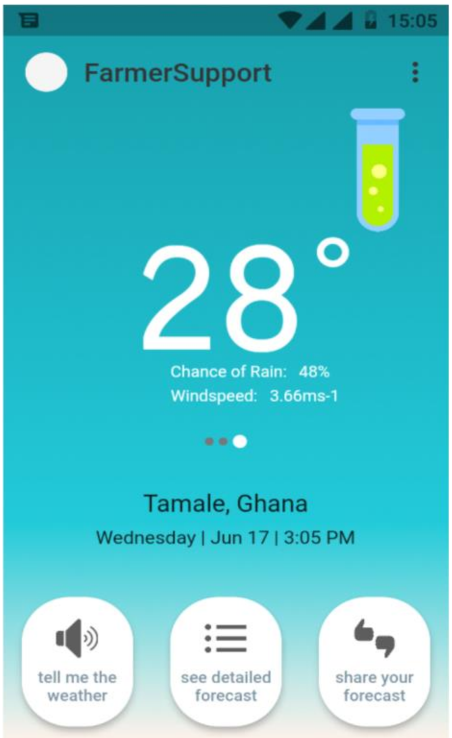
This is the first page you see when you start the app

Page 2

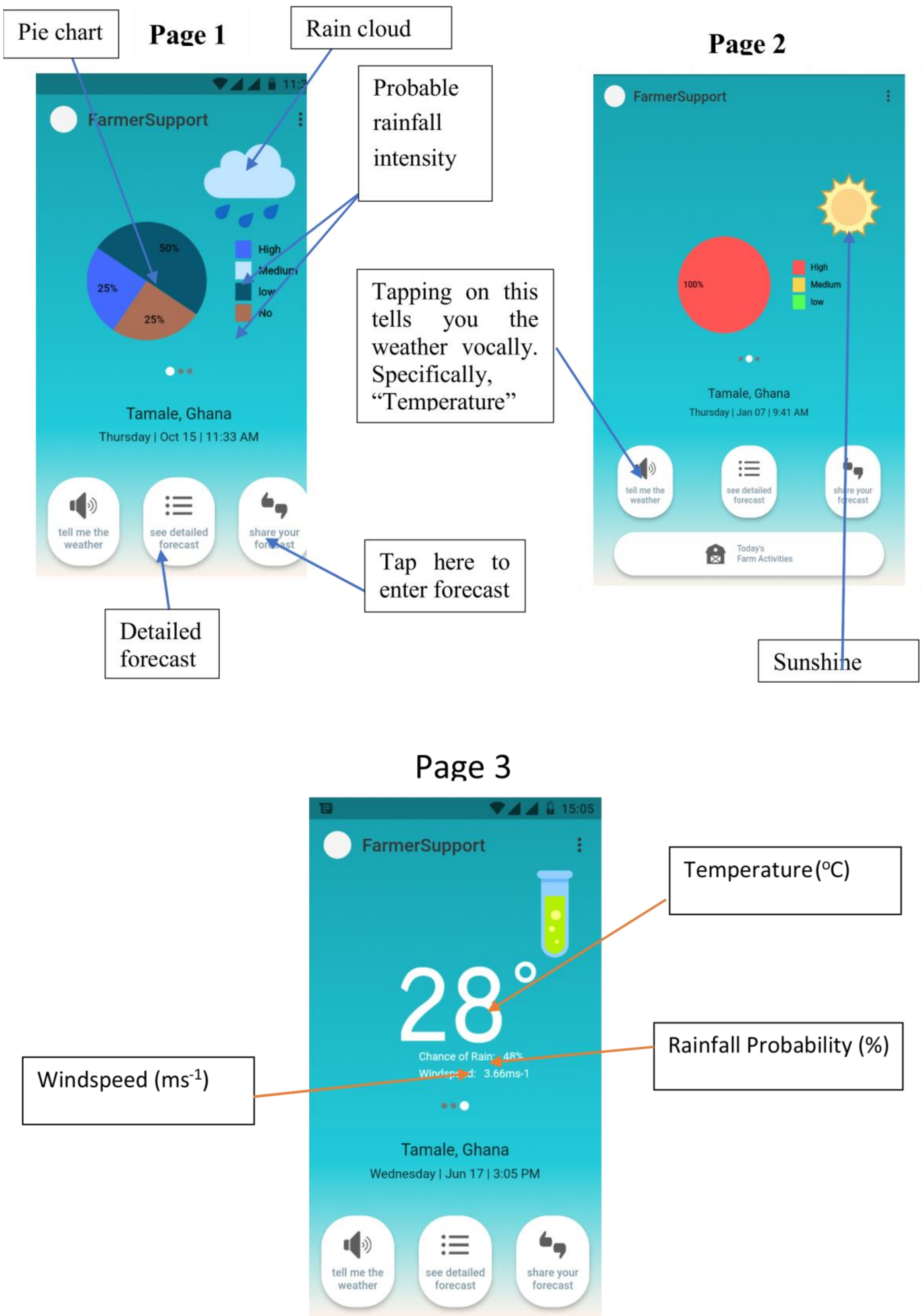
By sliding left, you move to the next page “page 3”



Page 3



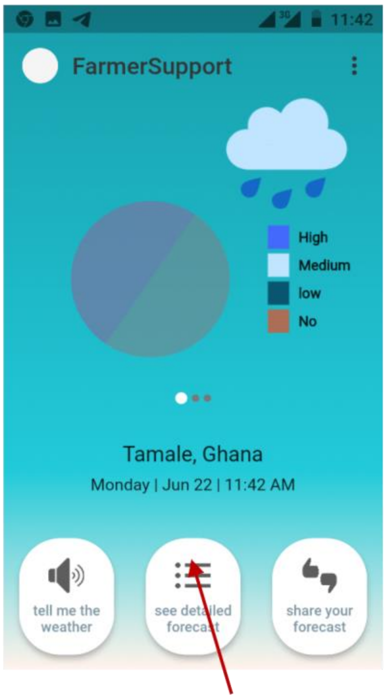
1.7 FEATURES OF THE APP



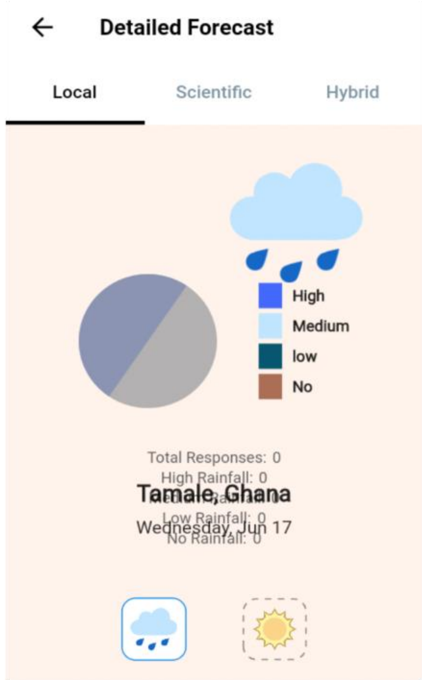
Page 1 shows a summary of the probability of rain as predicted by the farmers using indigenous indicators. If the greater proportion of the farmers think there will be rains, then the colour associated with “High” will take the greater proportion of the pie chart. For example, if 10 farmers input their predictions into the app, Assuming 8 out of the 10 thinks it will rain heavily then you will see that the colour associated with “High” will cover (80%) of the pie chart meaning the probability of rain is very high. (80% chance of rain). As shown in the pie chart on “Page 1”, 50% think that there will be rains of low amount 25% thinks there will high rainfall and 25% thinks there will be no rains at all. Page 2 displays sunshine predictions on a pie chart as well. Page 3 also shows a summary of rainfall and sunshine parameters.

1.8 Detailed Forecast Page

Page 1 local data



From your home page, tap to open your Detailed forecast

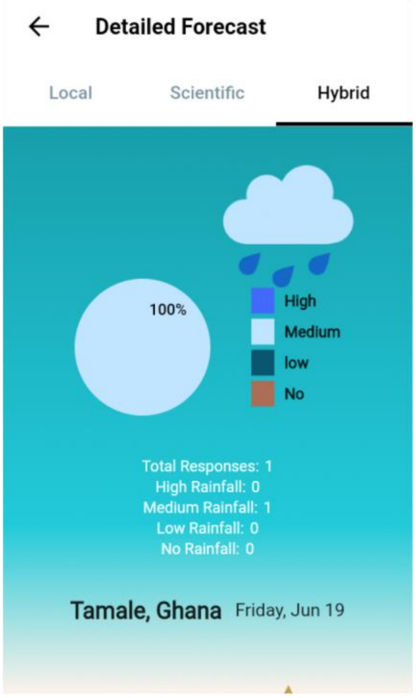


This indicates the number of responses and the intensity of rain predicted

Page 2 scientific data

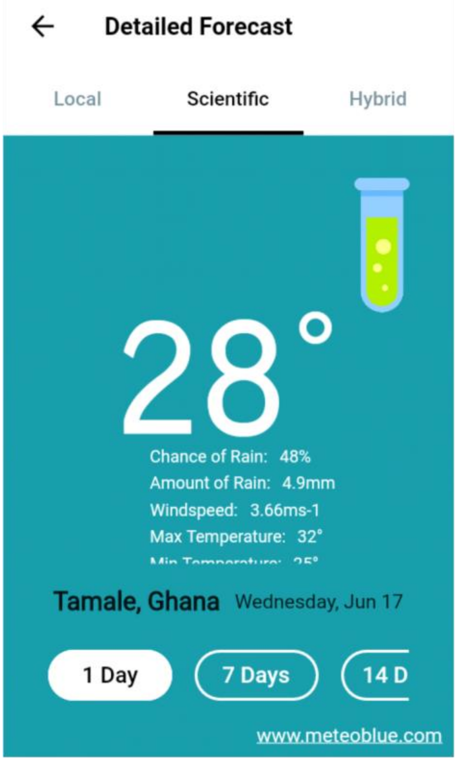
This page shows the scientific forecast in 1 day, 7 days and 14 days

Page 3 Hybrid data

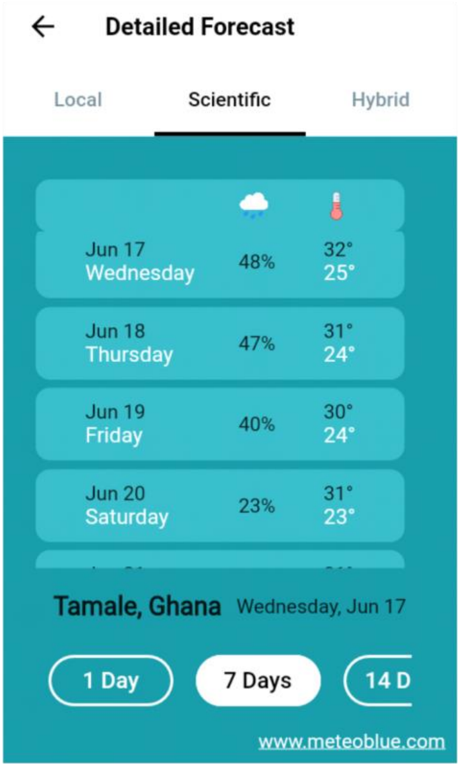


This page displays a combination of both local and scientific forecast

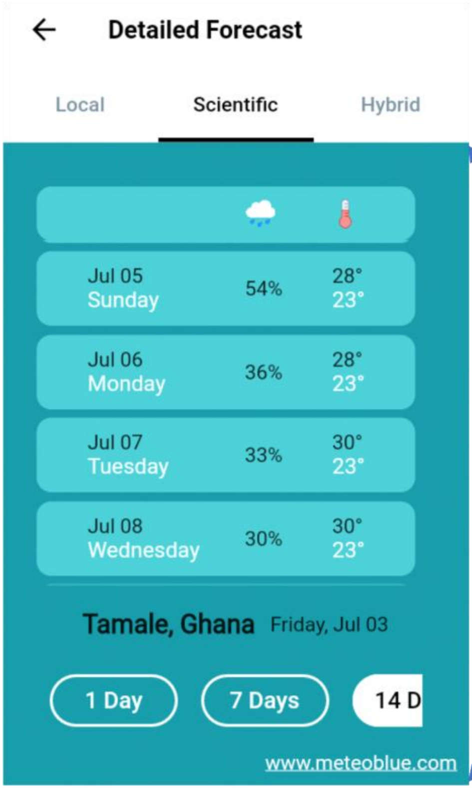
1.9 Scientific Forecast



1 Day forecast displays the weather in terms of temperature, rainfall amount and the probability of rainfall



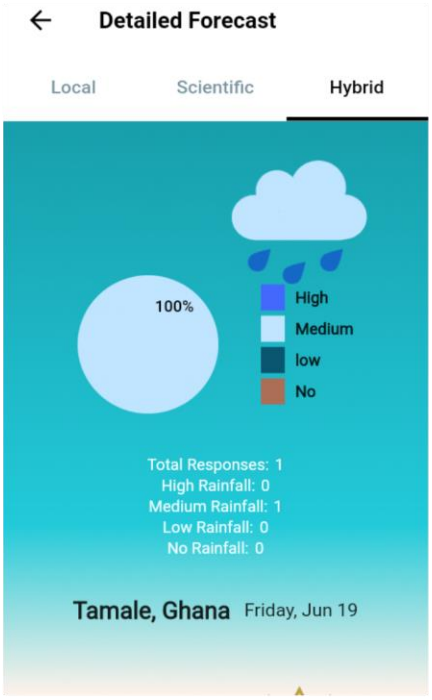
The 7 Days forecast displays the weather in terms of temperature and rainfall probability for the next 7 days. This enables the farmer to plan 7 days ahead



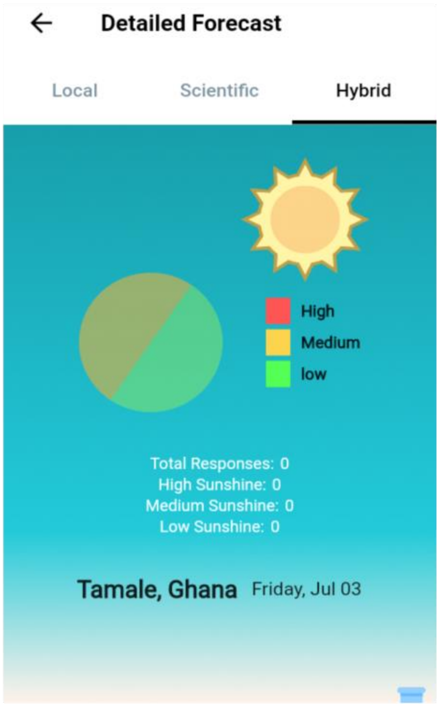
The 14 Days forecast displays the weather in terms of temperature and rainfall probability for the next 14 days. It helps the farmer to plan 14 days ahead.

1.10 Hybrid Forecast

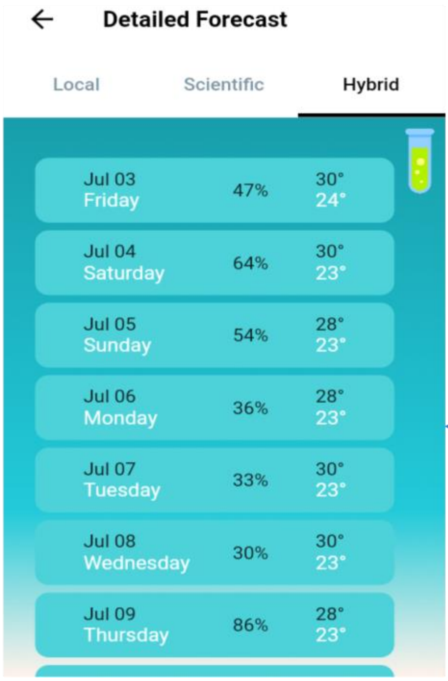
On the hybrid forecast page, the first page you see is the local rainfall information. Slide up to view the other pages.



Displays local Rainfall information

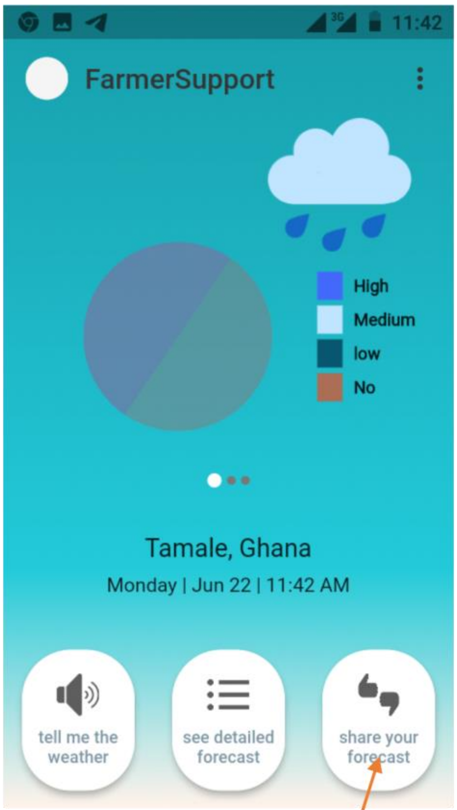


Displays local sunshine information

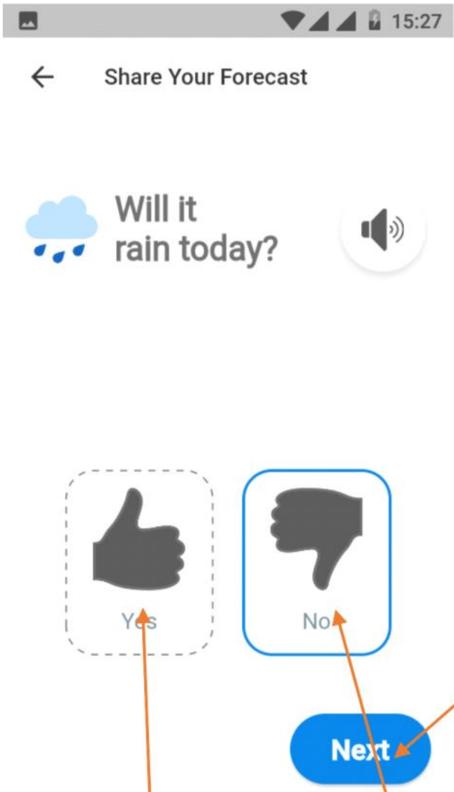


Displays 14 days scientific Rainfall information

1.11 How to Enter Predictions



From the home page, tap on share your forecast to input your predictions

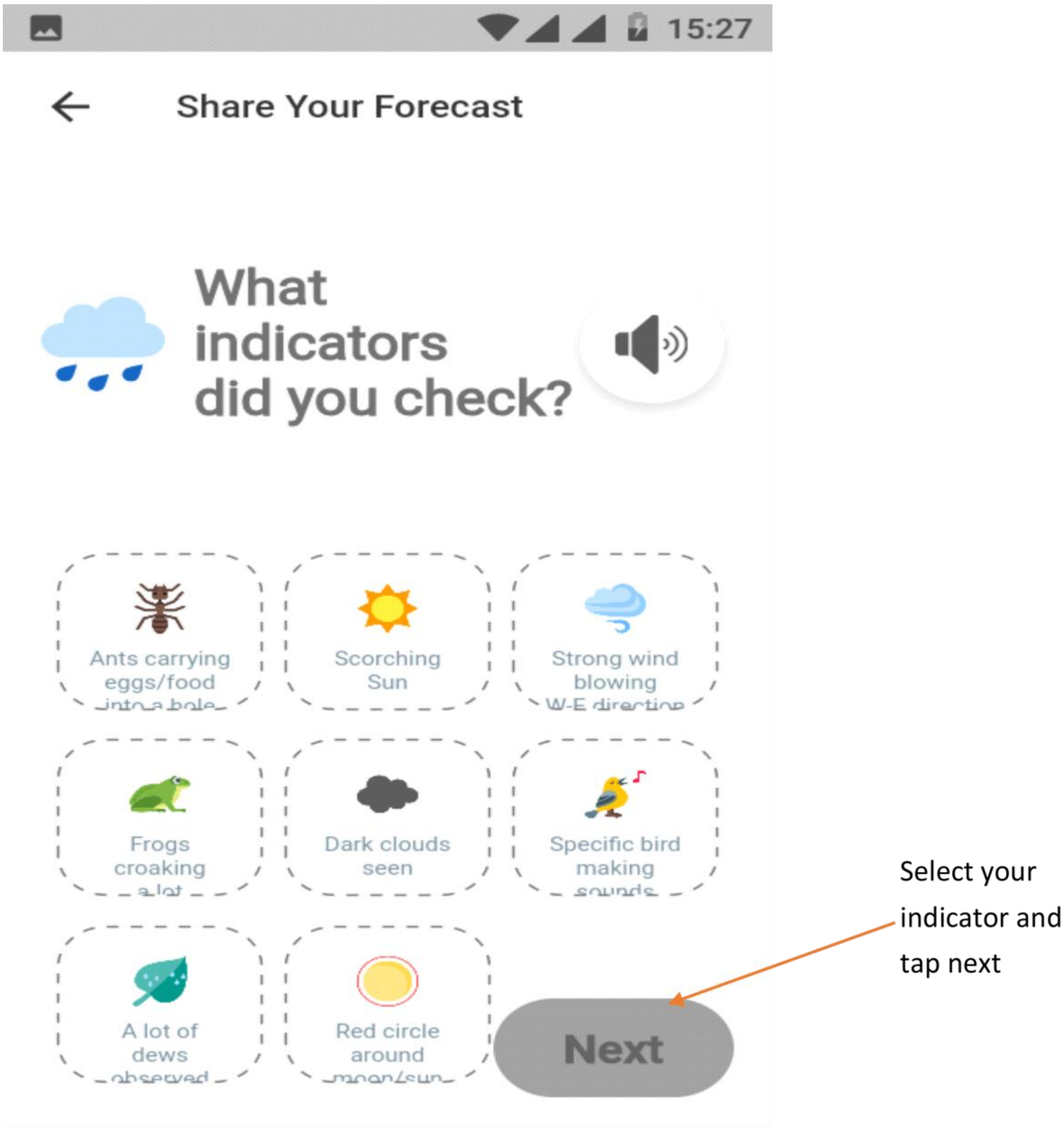


After selecting your option, tap next to move to the next page

Taping on the thumbs-up means “yes it will rain”

Taping on the thumbs-down means “no it won’t rain”

1.12 Rainfall Indicators



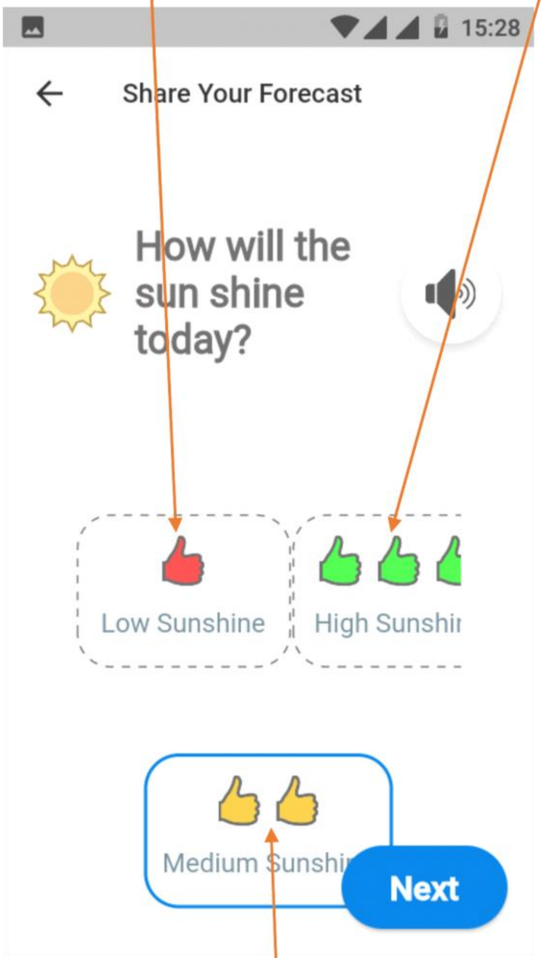
In case you choose "yes it will rain", then you have to select the indigenous indicator which influenced your decision i.e "what indicators did you check"?

e.g. If you saw ants moving from lower grounds to higher grounds and this is the reason why you think it will rain then you tap on ant and tap next

1.13 Predicting the Intensity of Sun Shine

Tap on 1 thumb -up if you think the sun shine will be low

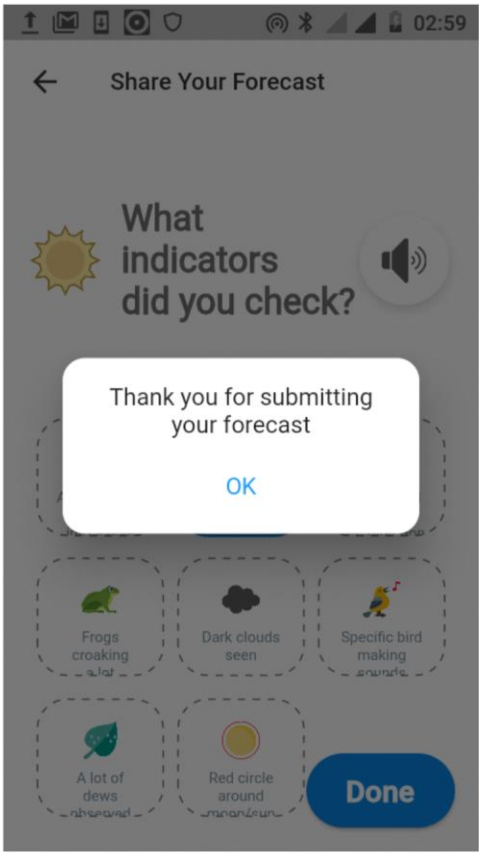
Tap on 3 thumbs-up if you think the sun shine will be high



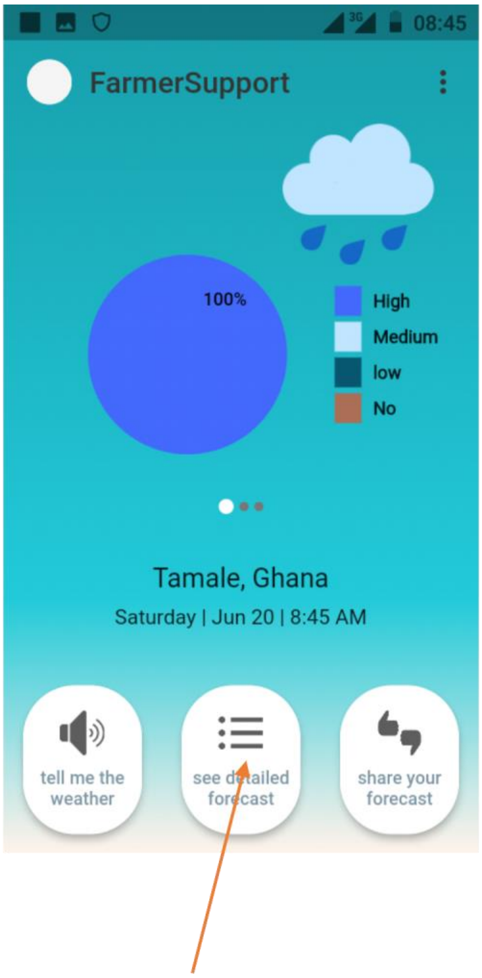
Select your indicator and tap done

Tap on 2 thumbs-up if you think the sun shine will be medium

1.14 Final Stage of Entering Prediction



After you have taped on done this is the screen that appears, tap on ok and this returns you back to the home page



You can tap on detailed forecast to view your input.

Appendix B: Focus Group Discussions - Experimental Farmers

This checklist was used as a guide for a focus group discussion with the farmers after the implementation of the FSApp. The checklist helped to capture the uptake level of the farmer of the training, the understanding that farmers had for using the app and the chances that farmers made to the agricultural activities and livelihoods

SECTION 1: How does the co-production of climate information services lead to behavioural changes of farmers in relation to agricultural decision-making?

1. **what level of satisfaction did you derive from participating in the training and implementation processes?**

2. **Were you able to use forecasts information in agricultural decision?**
   Yes / No
   How were you able to use forecasts? Give details where it helped

3. **What did you think about the training on the use of the FSApp?**

4. **Has the co-production of information improved forecast information?**
   Yes /No Explain

5. **Which platform (App/TV/Radio/Newspaper) do you currently use for forecasts information? Explain**

6. **Are you happy with forecast information from the FSApp?**

7. **Is the Farmer Support more suitable than the formal platform used? Explain**

8. **What was your confidence level in dealing with weather problems for crops after the training? Why?**

9. **Does the co-production improve information ownership and trust in sharing weather forecasts information with family, relatives and other farmers? Explain your answer**

10. **To what extend does co-production of the climate service meets the following criteria?**
    How will you rate this on a scale of 1-5?

1	2	3	4	5
Not at all				**Very much**

Was the forecast available?

- **a.** Were the forecasts provided timely and in time for farming operations?
- **b.** Were the provided forecasts trustworthy (credible) to you?
- **c.** Were the forecasts flexible in terms of access and communication?

11. Have you made any changes in your farming or livelihoods activities because of your attendance at the training on the FSApp?
Yes No

Explain your answer giving examples of changes made and reasons for making those changes

12. What are your major behavioural changes after training as an effort of co-producing climatic information services?

Statements	**Rate on a scale of 1 to 5 ("Very low 1" – "Very high 5")**	**Any indicators of change**
My awareness level about climate variability has increased after training and app implementation		
I access forecast information more frequently after training		
My forecasts uptake (use) has increased after the training		
I use both traditional and scientific forecast for my daily weather-related decision after the training and implementation		
My preparedness level to climate risks has been better after the implementation of the FSApp		

13. Mapping your behavioural change:
Did you or will you be using forecasts information for changing any of the decisions to adjust/adapt weather phenomena/or for adaptive agricultural decisions?
Yes No

If yes, map the changes that you did based on forecasts information from the FSApp:

Decisions points	**Yes/No/NA**	**Identify specific example and link with impacts (in terms of capital)**
Changed of acreage cultivated		
Change of crop variety		
Change of planting date		
Change date of weeding		
Change decision for buying inputs		

Change date of fertilizer application		
Change date of pesticide application		

SECTION 2: What are the key impacts of climate service co-production on livelihood resources (human, natural, physical, financial and social) of smallholder farmers?

1. Do you agree with the following statements?

Statements	**Rate on a scale of 1 to 5 (“Very low 1” – “Very high 5”)**	**Identify specific examples and link them with behavioural changes**
Human Capital		
I have acquired new knowledge and skills about forecasts information access, uptake and decision-making		
I am able to take farming decisions independently based on weather forecasts information (capacity)		
I have improved my capacity for interpreting climate information		
I have gained experience in using traditional and scientific forecasts information for agricultural decision-making		
My awareness on climate variability has increased		
Women participation and voice in agricultural decision-making has increased after the training		
Natural Capital		
My use and management of land and water resources has improved after the training		
Social capital		
After participation in the training, my social network has increased		
After participation in the training, I can provide forecasts assistance to peer farmers		

2. Who do you think is responsible for this climate change?

- Humans
- Nature
- Both
- I don’t know
- Other

Any reasons...

3. How much do you think that climate change threatens your life and livelihood?

How will you rate this on a scale of 1-5?
1 2 3 4 5
Not at all **Very much**

4. Based on the information you received, how secure do you feel now about your farming and food availability?

How will you rate this on a scale of 1-5?
1 2 3 4 5
Not at all **Very much**

5. Based on information received, were you able to make decisions that you otherwise would not be able to do so. Yes No Don't know **Briefly describe some:**

6. Based on your aspect of water and climate hazards, how likely is it for you to continue maintaining doing farming? Give reasons for your answer.

How will you rate this on a scale of 1-5?
1 2 3 4 5
Not at all **Very much**

7. Do you think climate variability has an impact on the sustainability of your agricultural practices? Explain How and why do you think so.

8. would you continue to use the FSApp? Yes/No why

9. Would you be prepared to pay for climate information services in future? Yes No

Why?

Appendix C: Questionnaire for Evaluation of the Outcome of the Implementation of the FSApp.

SECTION 1: GENERAL INFORMATION

Date: ..../………/2020

Name of the community;

Name of recorder:

S1Q1: Respondent's name ____

S1Q2: Gender: male female
S1Q3: Age group: <20 20-29 30-39 40-49 50-59 60 and over
S1Q4: Years of farming experience: 0-10 11-20 21-30 31-40 above 40
S1Q5: Total cultivated land: -------------- (Acre)

SECTION 2: How does the co-production of climate information services lead to behavioural changes of farmers in relation to agricultural decision-making?

S2Q1: Did you attend the training on the implementation of the FSApp?
Yes No
If yes, did you attend all the sessions? Yes No

If No, Give reasons why not
…………………………………………………………………………………………
…………………………………………………………………………..………………….

S2Q2: How long were you involved in the training and the implementation process in general?

____

S2Q3: what level of satisfaction did you derive from participating in the training and implementation process.

How will you rate this on a scale of 1-5?
1 2 3 4 5
Very dissatisfied **Very satisfied**

S2Q4: Are you currently receiving forecasts from the FSApp? Yes No
If no, Why?
....
....
....
......

S2Q5: Were you able to use forecasts information in agricultural decision? Yes No

How were you able to use forecasts? Give details where it helped

………………………………………………………………………………………………
……………………………………………………………………………………………

If no, why? Explain
....
....
....
......

S2Q6: What did you think about the training on the use of the FSApp?
....
....
....
......

S2Q7: Has the co-production of information improved forecast information? Yes No **explain?**
....
....
....
......

S2Q8: Which platform (App/TV/Radio/Newspaper) do you currently use for forecasts information? Explain Why?
....
....
....
......

S2Q9: Are you happy with forecast information from the FSApp?

How will you rate this on a scale of 1-5?
1 2 3 4 5
Very unhappy **Very happy**

S2Q10: Is the Farmer Support more suitable than the formal platform used?

How will you rate this on a scale of 1-5?
1 2 3 4 5
Very unsuitable **Very suitable**

Give reasons for the answer
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………

S2Q11: What was your confidence level in dealing with weather problems for crops after the training?

How will you rate this on a scale of 1-5?

1 2 3 4 5

Very low **Very high**

Explain.

....
....
....
....

S2Q12: Does the co-production improve information ownership and trust in sharing weather forecasts information with family, relatives and other farmers?

How will you rate this on a scale of 1-5?

1 2 3 4 5

Not at all **Very much**

Explain your answer

…………………………………………………………………………………………
…………………………………………………………………………………………

S2Q13: To what extend does co-production of the climate service meet the following criteria?

Evaluation criteria	**Not at all 1**	**2**	**3**	**4**	**Very much/Excellent 5**	**Can't say**
Was the forecast available?						
Were the forecasts provided timely and in time for farming operations?						
Were the forecasts specific enough for decision-making?						
Were the forecasts usable for decision-making (actionable)?						
Were the provided forecasts trustworthy (credible) to you?						
Were the forecasts flexible in terms of access and communication?						

S2Q14: Have you made any changes in your farming or livelihoods activities because of your attendance at the training on the FSApp?

Yes No

If yes, tell us about specific changes in your farming or livelihood activities after the training.

Changes made	***Why***	***When***

If no, why not?

....
....
....
......

S2Q15: What are your major behavioural changes after training as an effort of co-production climatic information services?

Statements	**Rate on a scale of 1 to 5 (“Very low 1” – “Very high 5”)**	**Any indicators of change**
a. My awareness level about climatic change impacts and variability has increased after training and app implementation		
b. I access forecast information more frequently after training		
c. My forecasts uptake (use) has increased after the training		
d. I use both traditional and scientific forecast for my daily weather-related decision after the training and implementation		
e. My preparedness level for climate risks has been better after the implementation of the FSApp		

S2Q16: Mapping your behavioural change:
Did you use forecasts information for changing any of the decisions to adjust/adapt weather phenomena/or for adaptive agricultural decisions?
Yes No

If yes, map the changes that you did based on forecasts information from the FSApp:

Decisions points	**Yes/No/NA**	**Identify specific example and link with impacts**
a. Changed of acreage cultivated		
b. Change of crop variety		
c. Change of planting date		
d. Change date of weeding		
e. Change decision for buying inputs		
f. Change date of fertilizer application		
g. Change date of pesticide application		
h. Change date of harvest		

If no, why not? Give reasons

……………………………………………………………………………………………
…………………………………………………………………………………………….

SECTION 3: What are the key impacts of climate service co-production on livelihood resources (human, natural, physical, financial and social) of smallholder farmers?

S3Q1: Do you agree with the following statements? How will you rate the following?

Statements	**Rate on a scale of 1 to 5 ("Very low 1" – "Very high 5")**	**Identify specific examples and link them with behavioural changes**
Human Capital		
a. I have acquired new knowledge and skills about forecasts information access, uptake and decision-making		
b. I am able to take farming decisions independently based on weather forecasts information (capacity)		
c. I have improved my capacity for interpreting climate information		
d. I have gained experience in using traditional and scientific forecasts information for agricultural decision-making		
e. My awareness on climate variability has increased		

f. Women participation and voice in agricultural decision-making has increased after the training		
Natural Capital		
a. My use and management of land and water resources has improved after the training		
Physical capital		
a. My food production and average yields have increased after the training		
b. Forecast information also helps in livestock and aquaculture ponds management activities		
Financial Capital		
a. Reduced my input costs such as labour, irrigation, fertilizer and pesticides, etc.		
b. Reduced financial loss from sudden weather and climate risks such as droughts and floods		
Social capital		
a. After participation in the training my social network has increased		
b. After participation in the training I receive better assistance from peers		
c. After participation in the training I can provide forecasts assistance to peer farmers		
d. My social relationship has increased after training		
e. Power relationship between men and women has improved after the training		
f. Interactions among young and older farmers has been increased after the training		

S3Q2: Climate information services will have impacts for resilient livelihood practices of farmers. To investigate this issue, how do you agree with the following statements?

Statements	Yes/No/NA	Identify specific example and link to behavioural change and impacts (in terms of capitals)
a. My agricultural decisions are appropriate considering climate phenomena after the implementation of the App		

b. Forecasts information has helped me to choose crop and climate-resilient crop variety		
c. Through the use of forecasts information, I can better adapt to hydro-climatic variability and associated risks after the training		
d. My disaster preparedness and emergency responses are better after the training		
e. I can better design/plan my daily households and farming activities after the training		
f. The forecasts information was also helpful for the collection of harvested crops from fields		
g. The forecast information was also helpful for organizing social affairs and personal travel		

S3Q3: Do you believe that the climate is changing?

Yes No Don't know

S3Q4: Who do you think is responsible for this climate change?

- Humans
- Nature
- Both
- I don't know
- other reasons...
..

S3Q5: How much do you think that climate change threatens your life and livelihood? How will you rate this on a scale of 1-5?

1 2 3 4 5
Not at all **Very much**

S3Q6: Based on the information you received, how secure do you feel now about your farming and food availability?

How will you rate this on a scale of 1-5?

1 2 3 4 5
Not at all **Very much**

S3Q7: Based on information received, were you able to take decisions that you otherwise would not be able to do so

Yes No Don't know

If YES, briefly describe some:
....
....
....

S3Q8: Based on your aspect on water and climate hazards, how likely is it for you to continue maintaining doing farming?

How will you rate this on a scale of 1-5?

1 2 3 4 5
Not at all **Very much**

Can you explain your answer?
....
....
....
....
....

S3Q9: Do you think climate variability has an impact on the sustainability of your agricultural practices? Explain How and why do you think so.
....
....
....
....

S3Q10: would you continue to use the FSApp? Yes/No why?
……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………………………………………………………………………….

S3Q11: Would you be prepared to pay for climate information services in future? Yes No

Give reasons for your answer
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
………………………………………………………………………………

Appendix D: Additional Indicators Identified During the Studies

Indicator	Indications
Ducks flapping wings early morning	There will be rains in a few minutes
A cluster of earthworms moving about near a bush in the evening after a short dry spell	There will be rains that down
Black ants moving their eggs from one place to another	Rains
Strong winds blowing from West to East	Rains
Reddish appearance of the moon with clouds at one side	Rains
A very warm weather	Rains
Specific birds' crawl in the bush	Rains
Presence of ruminants in the house at unusual times	Rains
Unusual sounds of frogs in the afternoon	Rains
Extreme scorching sun	Rains
Jalenjahe/duck (*Anas platyrhynchos*) faces East when swimming	Rains
The return of flock of birds to their nest in the evening after leaving the nest in the morning	Enough rains that season
Formation of clouds coupled with little wind	Heavy rains
Presence of armyworm pupa	Drought
Snails remaining /hiding in their shells	Drought
Jalenjahe/duck (*Anas platyrhynchos*) faces West when swimming	Drought
Absence of strong wind at the onset of rains	Normal season