BRIDGING SCIENCE AND SOCIETY

Tailor-made Hydroclimatic Information Service with
Farmers in Lower Bengal Delta, Bangladesh

Uthpal Kumar

Propositions (6)

1. Climate service needs assessment is not a single-step process.
   (this thesis)

2. Short- and medium-range weather forecasts have a higher value than the seasonal forecasts to smallholder farmers.
   (this thesis)

3. Corruption is the main challenge for climate change adaptation in developing countries.

4. Vulnerability is socially constructed.

5. Social media has increased social tension.

6. Covid-19 pandemic has created social inequity.

Propositions belonging to the thesis entitled:
Bridging Science and Society: Tailor-made Hydroclimatic Information Service with Farmers in Lower Bengal Delta, Bangladesh

Uthpal Kumar
Wageningen, 29 June 2021

BRIDGING SCIENCE AND SOCIETY

Tailor-made Hydroclimatic Information Service with Farmers in Lower Bengal Delta, Bangladesh

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Uthpal Kumar

Thesis

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Prof. Dr A. P. J. Mol,
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Abstract

The farming communities living in the Lower Bengal Delta, Bangladesh are vulnerable to hydroclimatic variability. Farming decisions are becoming risky due to unpredictable weather patterns. The southwest region of Bangladesh, located in the heart of the Lower Bengal Delta, is known as an ecologically rich and productive agriculture zone. At the same time, smallholder farming communities are confronted with recurrent hydroclimatic events such as cyclones, storm surges, tidal flooding, and salinity intrusion among others. These events severely affect the agricultural income, livelihood, and food security of farming communities. Improved management of these hydroclimate risks is necessary to improve the livelihood and food security of the smallholders. Hydroclimate information services and technology hold the potential to help smallholders to manage hydroclimatic risks through informed agricultural decision-making. However, there is a scientific challenge for developing services and bridges between the available model-based forecasts and the local context and capabilities. The central question is how hydroclimatic information services can be tailored in ways that local farmers find useful in decision-making processes for their crops and livelihood activities. Another transdisciplinary challenge is balancing information service providers and end-users, integrating social science and climate science perspectives. Understanding end-user needs and capacity, local knowledge institutions, and policy are also fundamental challenges for the co-production of services for sectoral end-users and improving the value of forecasts information. There is a need for timely, accurate, and effective hydroclimatic information services mechanisms. The existing information services are largely developed from a top-down perspective. A bottom-up approach, shaped by users' requirements, engagement and capacity building has not been attempted yet. In this dissertation, I aim to co-produce hydroclimatic information services with smallholder farmers in the lower Bengal Delta in Khulna, Bangladesh. A mixed-methods transdisciplinary research approach was applied to study current knowledge gaps that exist regarding (i) farmers' practices and the role of available information, (ii) hydroclimatic information needs of smallholders, (iii) co-production of information services with and for smallholder farmers, and (iv) willingness to pay for location- and time-specific climate information services for wider uptake, improved agricultural practices, and service sustainability. This study confirms that there is a potential for need-based tailored information services for smallholders. However, farmers' information needs assessment is not a single-step process. This requires iterative interaction and capacity building. The co-production study shows that hydroclimate information services through actors' collaboration, capacity building of farmers, and extension officers at farmer field school lead to better understanding, accessibility, and uptake of weather and climatic information services in agricultural decision-making. The co-produced services also have better economic and environmental outcomes due to less use of fertilizer and pesticides in crop fields, and reduced production costs. A study on farmers' willingness to pay (WTP) for climate services indicates a higher WTP after receiving training and joining in the participatory co-production process at field schools. Finally, the co-production of hydroclimatic information service has eventually improved the management of field-crop, livestock, aquaculture, and disaster risks reduction of smallholder farmers for sustainable agriculture and livelihood practices in the Lower Bengal Delta.

Table of Contents

Chapter 1

General Introduction

Chapter 1

General Introduction

1.1 Background and Problem Statement

Peri-urban smallholder farmers are very vulnerable to hydroclimatic variability and climate change impacts in the Bengal Delta (Dasgupta et al., 2015b, Huq et al., 2015, Rabbani et al., 2010, Islam and Hasan, 2016, Kabir et al., 2016). Farmers in the delta depend on the seasonal rainfall for agricultural practices (Kabir et al., 2016, Bala and Hossain, 2010, Mo, 2008, MoEF, 2008). They suffer from recurrent hydroclimatic events such as heavy rainfall, drought, cyclones, storm surge, waterlogging, and salinity intrusion (Huq et al., 2015, Uddin et al., 2014, DAE, 2018b, Kabir et al., 2016). Agricultural practices of smallholders are becoming challenging due to unpredictable weather events (Islam and Hasan, 2016, Huq et al., 2015, Khanom, 2016). These hydroclimatic variabilities severely affect agricultural income and livelihood security, especially poor farming communities (Huq et al., 2015, Mondal et al., 2015). While hydroclimatic information services with available information and communication technology (ICT) can potentially assist farmers to manage these hydroclimatic risks and informed decision-making, currently, smallholders do not have access to location- and time-specific hydroclimatic information services in advance time-scale and a meaningful (useful and useable) way (Islam et al., 2013).

The development of hydroclimatic information services has the potential to support the planning and management of agricultural activities (Gbangou et al., 2020a, Paparrizos et al., 2020a, Naab et al., 2019, Nyadzi et al., 2018, Rahaman et al., 2020, Kundu et al., 2020). Here hydroclimatic information service is defined as the production, translation, dissemination, and usage of the weather, climate, and water-related information to support societal decision-making (Vedeld et al., 2019, Kruk et al., 2017, Amwata et al., 2018, Vaughan and Dessai, 2014). In this dissertation, I used hydroclimatic information services and climate information services (CIS) as an alternative expression. However, the currently available hydroclimate information services have several limitations in understanding, timeliness, accessibility, and reliability to local smallholders (Islam et al., 2013, DAE, 2018b, Fakhruddin et al., 2015, Chowdhury, 2005). A recent study conducted by the Agricultural Extension Department (DAE) observed that agricultural practices and decision-making (choice of crop, planting date, irrigation, etc.) are mostly dependent on farmers' local knowledge and traditional practices. The majority of smallholder farmers do not understand and use hydroclimatic information services shared through the traditional media such as television and radio (DAE, 2018b). The study indicates that farmers require more precise information such as daily, weekly, bi-weekly, monthly, and seasonal time-scale forecasts at the local level with farmers and extension officers training and capacity building (DAE, 2018b, Ahmed et al., 2019). Besides, information uncertainty and lack of socio-economic and personal capacity also limit smallholders from taking advantage of the publicly available information services (Archie et al., 2014, DAE, 2018b). This overall situation negatively impacts the delta people's food production and livelihood security (Huq et al., 2015).

There is a scientific challenge for hydroclimate information services for smallholders and bridges between the available model-based forecasts and the local context and capabilities. Thus the central question is how hydroclimatic information services can be co-produced in ways that local farmers find useful in decision-making processes for their crops and livelihood activities. The co-production of hydroclimatic information services offers benefits to the farmers from the favorable climate conditions and reduces losses from unfavorable climate conditions (Klemm and McPherson, 2017). Another significant transdisciplinary challenge is balancing service providers and users, integrating social science and climate science perspectives (Klemm and McPherson, 2017). Understanding farmer needs and capacity, decision-making processes, local institutions, and policy are also fundamental challenges for the co-production of hydroclimatic information services for specific sets of decisions and improving the value of forecasts information services for smallholder farmers (Kumar et al., 2020a). Finally, developing an effective communication platform through bridging the gaps between local service providers and their organizational policy perspective is another complex transdisciplinary challenge for the co-production of information services involving climate scientists, stakeholders, and end-users.

In this dissertation, I aim to co-produce hydroclimatic information services with smallholder farmers in the lower Bengal Delta in Khulna, Bangladesh. To achieve this broad research objective, I applied four research steps: (1) understanding farmers practices, accessibility, and role of information in agricultural decision-making; (2) hydroclimatic information needs assessment of farmers, (3) co-producing climate information services with and for farmers, (4) assessment of willingness to pay for climate information services of farmers. A transdisciplinary research approach was followed in each step of the research process to bridge gaps between meteorological experts, extension departments, researchers, and local farmers. I organized two farmer field schools to facilitate the fundamental research and co-production process involving scientists, service providers, and end-users farmers in participatory, collaborative interactions. I presented knowledge gaps, research objective, research questions, conceptual framework, case description and methods, and outline of this dissertation in the following sections.

1.2 Knowledge Gaps and Research Focus

Skillful location- and time-specific climate information can positively support agricultural decision-making (Christel et al., 2018, Coulibaly et al., 2015a, Dhankar, 2002, Kushwaha et al., 2008, Sivakumar et al., 2014). However, existing climate services are mostly narrowly framed, following one-way supply-driven models, and are not readily useable and useful for the smallholders' decision-making (Bremer et al., 2019, Vedeld et al., 2019, Vincent et al., 2018). Thus, service co-production is an essential step to understand user-specific needs and bridge gaps among producers and end-users (Christel et al., 2018, Coulibaly et al., 2015, Naab et al.).

In this dissertation, I addressed knowledge gaps that contribute to limited access to reliable hydro-climate information for informed decision-making of the smallholders in the Bengal Delta. These knowledge gaps are lack of understanding of:

1) Smallholders’ current practices, information accessibility, perceived quality, and role of information in agricultural decision-making.
2) Information needs for agricultural decision-making of the smallholders in the Bengal Delta.
3) The co-production of climate information services with smallholders for better uptake of scientific forecasts in agricultural decision-making.
4) Willingness to pay (WTP) for climate information services of smallholders for a future business model and service sustainability in the study area.

1.3 Objective and Research Questions

The objective of this dissertation is to explore smallholders' information needs and co-production of location- and time-specific climate information services with smallholder farmers to support agricultural decision-making in peri-urban Khulna, Bangladesh. The overall research objective is accomplished by answering the following four questions (Figure 1.1).

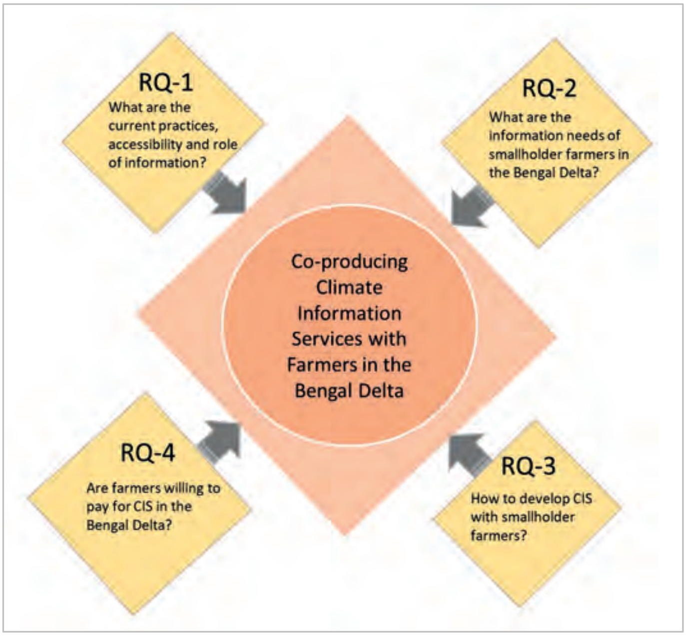

Figure 1.1. The four research questions addressed in this dissertation for the co-producing hydroclimatic information services with smallholder farmers in the Lower Bengal Delta.

- *RQ-1. What are existing knowledge, local practices, and accessibility to hydroclimatic information of the peri-urban farming communities in the Lower Bengal Delta (Chapter 2)*

This question aims to map and understand the information sources available in the study area, identify the limitations of the existing sources, and suggest ways to better design information services for increased uptake at the local level. A three-fold sub-question is answered: (i) what information is currently available to farmers to inform their agricultural practices and decision-making? (ii) to what extent do farmers perceive the available hydroclimatic information as helpful in responding to water- and weather-related stresses? (iii) how has the available information influenced farmers' decision-making?

- *RQ-2. What kind of hydroclimatic information is needed by smallholder farmers communities for sustainable agricultural practices in the study area (Chapter 3)*

This question explores the information needs of farmers by addressing two sub-questions: (1) what kind of information is needed by the peri-urban delta farmers, and (2) whether information needs have any temporal dimension that changes with time following capacity building during co-production of information services. The answer to these research questions provides insight into understanding farmer information needs, which is vital for the co-production of climate information services for smallholders in agricultural decision-making. This research will help researchers and policymakers to understand climatic information needs in a developing context where farmers and extension services have limited training and skills or capacity.

- *RQ-3. What types of information platforms are effective and have the potential for co-producing climatic information services with farmers in the study area? (Chapter 4)*

This question investigates how the co-production of climate information services through forecasts visualization and communication can improve forecast uptake for smallholder farmers' climate-sensitive decision-making. To answer this question, I applied the farmer field school (FFS) approach to deliver 7-day, 14-day, and seasonal forecasts (3-months) information during the face-to-face meeting using printed paper and smartphone applications. This research will help researchers and service developers better design information and dissemination platforms for climate information services utilized by farmers and intermediaries interactions and capacity.

- *RQ-4: Are farmers willing to pay for participatory climate information services in the Lower Bengal Delta? (Chapter 5)*

This question aims to assess farmers' willingness to pay for weather and climate information services that were being co-produced for farmers in peri-urban Khulna, Bangladesh. A double-bonded dichotomous contingent valuation method is employed to estimate the farmers' willingness to pay (WTP) for participatory climate information services in the study area to answer this research question. This study provides empirical evidence about the willingness to pay for location-specific climate information services. This will assist scientists, service developers, and policymakers in co-developing a business model for climate information services in the Bengal Delta.

1.4 Scientific Approach and Methodology

1.4.1 Conceptual framework

The co-production of hydroclimatic information services is the central research concept of this dissertation. Here co-production refers to the multi-way interactions process between scientists, intermediary stakeholders, and end-user farmers for generating new hydroclimatic knowledge and services useable by decision-makers (Wall et al., 2017, Lemos and Morehouse, 2005, Bremer et al., 2019). Co-production of hydroclimatic information services is studied as a means to potentially support smallholder farmers in agricultural decision-making (Gbangou et al., 2020a, Vincent et al., 2020a, Vedeld et al., 2019, Vincent et al., 2018). Scholars report that co-production builds on trust and knowledge co-production through iterative interactions and capacity building that bridge existing gaps between the scientists and end-users (Vincent et al., 2020a, Kruk et al., 2017). A joint co-production effort confirms the construction of actionable knowledge (Mach et al., 2020, Sarku et al., 2020b, Ofoegbu and New, 2021, Gbangou et al., 2020a, Hegger and Dieperink, 2014, Vedeld et al., 2019). However, the existing co-production efforts narrowly addressed the existing gaps between producers' and end-users perspectives (Vincent et al., 2020a, Bremer et al., 2019). As a result, most of the information services to date have been failed to establish the potential benefits of co-production with usefulness and usability of information services (Bremer et al., 2019, Hewitt et al., 2017, Lemos and Morehouse, 2005). Besides, iterative interactions and capacity building of the intermediary and end-users are an integral part of a successful co-producing, hardly recognized by scientists in the previous climate services research and co-production process (Sultan et al., 2020, Moeletsi et al., 2013a, Zuma-Netshiukhwi et al., 2016).

Thus, there is little evidence of an explicit co-production process and uptake of forecast information by smallholders to manage hydro-climate risks and end-users needs and decision-making processes (Unganai et al., 2013). To overcome these existing inadequacies, Tall (2013) suggests five key facts for developing climate services based on success stories of the World Meteorological Organization (WMO) implemented under the Global Framework for Climate Service (GFCS). These are: 1) understanding needs of the end-users, 2) bridge the gap between forecasters and sectoral experts, 3) co-production to address end-user needs, 4) effective communication with end-users called 'the last mile' and, 5) assess and re-assess (evaluation). I addressed these five dimensions in the conceptual framework. In this dissertation, I hypothesize that organization of a users' platform is vital to identifying, understanding, and subsequently integrating farmers needs, engagements, capacity building, and feedback in the co-production process will result in a much comprehensive understanding, dissemination uptake of the information services (Figure 1.2).

The conceptual framework of the co-production also links visualization and communication as the major attributes to deliver information services and better uptake by end-users for agricultural decision-making (Lorenz et al., 2015, McCaslin et al., 2000, Drake et al., 2016, Ruginski et al., 2016, Nadav-Greenberg et al., 2008, Hansen et al., 2011, Roncoli et al., 2009) (Figure 1.2). Here, forecast visualization involves the translation of forecast information through graphs, visual images, and symbols to understand and enable them to uptake the information in decision-making with minimum education and knowledge on the scientific forecasts and technologies. Lack of forecast visualization might impact in understanding, communication, and interpretation of available scientific forecasts to smallholders' decision-making (Ruginski et al., 2016, Nadav-Greenberg et al., 2008). The language (English) and scientific terminology are often used in forecast prototypes constraining uptake by farmers (Pennesi, 2007, Misaki et al., 2018, Feleke, 2015). Besides, personal capacity such as gender, economic status, farming experience, farm size, farm types, and age factors also essential attributes of forecast uptake (Tall et al., 2018, Partey et al., 2020, Amwata et al., 2018). In this dissertation, I focused on visual forecast diagrams (7-days, 14-days, and seasonal) for service co-production as elaborated in Kumar et al. (2020a).

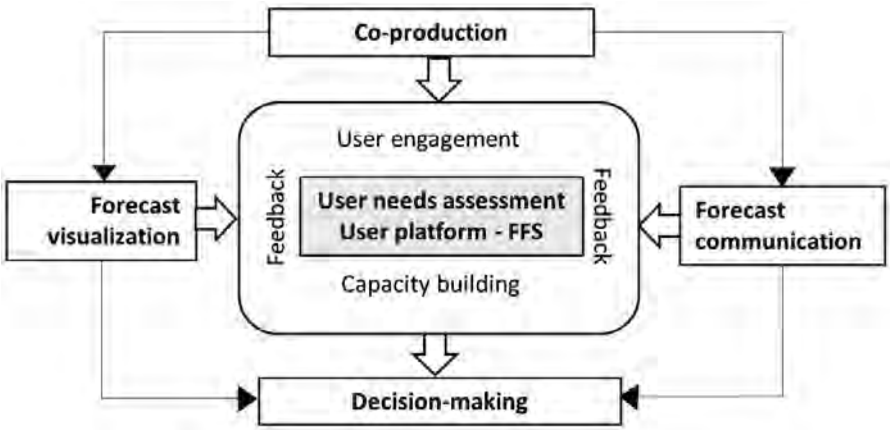

Figure 1.2. Conceptual framework of the co-production.

Effective communication asserts better uptake of forecasts and bridges the gap between scientists and farmers (Hansen et al., 2011, Roncoli et al., 2009). The ICT platform such as a smartphone apps is a useful ICT tool for information communication from developers to intermediary and end-users (Adamides and Stylianou, 2013, Cartmell-Thorp, 2016, Ashutosh et al., 2012). ICT-led platforms are more transparent through which useful information could be disseminated as widely and quickly as possible. I found that a social media app added value in the co-production process for delivering climate services with the local extension officers and farmers. They were already familiar with such information sharing platforms. For this study, I utilized the Facebook messenger app and face-to-face traditional communication methods to influence farmers' tactical and strategic decision-making.

Co-production requires interdisciplinary and transdisciplinary research action and practices (Mauser et al., 2013, Leon and Gotangco, 2013). To achieve the overall research objective, the case description and methodological outline are given in the following sub-sections.

1.4.2 Study area – the Lower Bengal Delta

The study is conducted in the Lower Bengal Delta in Khulna, Bangladesh (Figure 1.3). Khulna is located in the center of the Lower Bengal Delta between the 22°12-23°59 north latitudes and between the 89°14-89°45 east longitudes. It constitutes 4 389.11 sq. km and 2.97% land area of Bangladesh (BBS, 2013). The study area is part of Agro-ecological Zone 13: Ganges Tidal Floodplain. The total population of Khulna District 547 000 households. A total of 41% of households are involved in agricultural activities of which 63% are smallholders (BBS, 2019). Major crops cultivated in Khulna are hybrid (HYV) and local varieties of rice, jute, sesame, and vegetables. The primary land uses are single-crop (88%), double-crop (11%), and triple-crop (1%) (Rashid et al., 2017, Rashid et al., 2014).

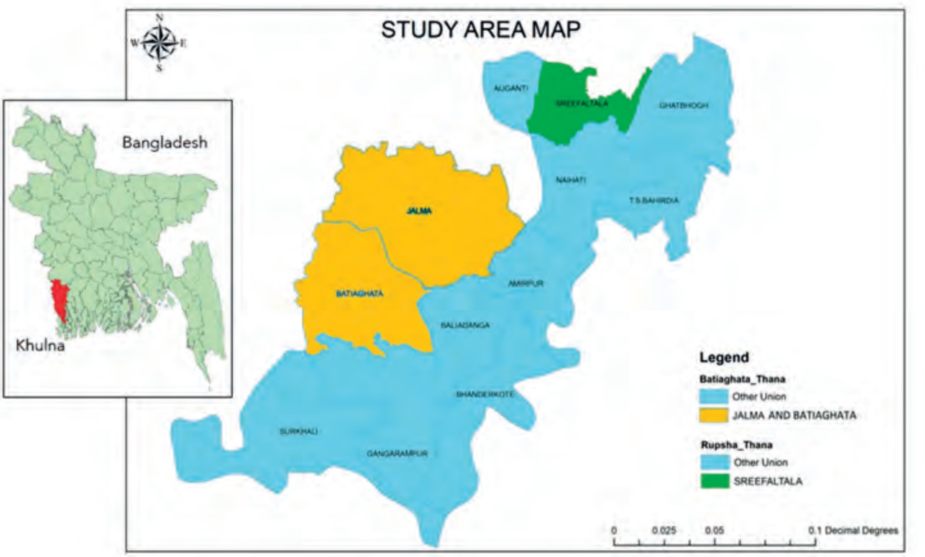

Figure 1.3. Location map of the study area in the Lower Bengal Delta of Peri-urban Khulna, Bangladesh. *Jalma*, *Batiagha Sadar* (yellow), and *Sreefaltala* (green) study sites were selected from Batiaghata and Rupsa sub-districts.

Khulna is located in a hot and humid subtropical climate zone (Shahid, 2010). The annual mean maximum and minimum temperatures are 35.5 °C and 12.5°C respectively (Rashid et al., 2019). The annual average rainfall over the period 1948 to 2018 was 1752.3mm (Kumar et al., 2020b). Khulna represents an increasing trend of hydroclimatic variability that significantly impacts crop production in the entire delta area (Hossain et al., 2014). About 70 - 90% of the annual rainfall occurs between May to October (Shahid, 2010). Studies show that interannual rainfall variability has been changed with a reduced monsoon season's length (Hossain et al., 2014, Paparrizos et al., 2020b). This has increased the pressure on delta farmers with regard to rainfed farming practices.

1.4.3 Research methods

I applied the farmer field school (FFS) approach as a user (farmers) platform for co-production. I followed a four-step research method. I used FFS as a center for farmers' engagements and data collection using participatory methods such as interviews, focus group discussion, participatory meetings, and farmers workshops. Figure 1.4 shows the step-wise research activity, data collection, analysis, and outputs connected to the four research questions.

FFS is a user platform and information center introduced by the Food and Agriculture Organization of the United Nations (FAO) in 1988 (Braun and Duveskog, 2011). FFS is widely used for agricultural knowledge co-production with farmers in Asia, Africa, Europe, Latin America, and the Caribbean (Charatsari et al., 2017, Suzanne Nederlof and Odonkor, 2006, Braun and Duveskog, 2011). Similar to other countries, FFS is widely used in Bangladesh for agricultural extension and technology transfer. A farmer field school generally consists of a group of farmers (~30) with a common interest that regularly meets a particular issue about agricultural activities and decision-making (Braun and Duveskog, 2011). According to the agricultural extension department (DAE), FFS is one of the main knowledge exchange platforms of Sub Assistant Extension Officer (SAAO) at the community level, named agricultural block. An agricultural block contains several farmer villages. An SAAO facilitates about 12 FFS in an agricultural block for information services (DAE, 2018a).

I organized two farmer field schools to engage farmers in the co-production process, where farmers and extension staff can interact for hands-on skills in understanding climate information services and better uptake information for agricultural decision-making. The FFS approach is followed in this dissertation for participatory interactions and learning with smallholders. The FFS platform also provided scope to smallholders for practical learning-by-doing field exercises in the study area (Pretty and Buck, 2002, Suzanne Nederlof and Odonkor, 2006). Frequent information sharing options and the usefulness of forecasts information were discussed weekly to build a strong community relationship and network through peer-to-peer sharing and discussion.

In this dissertation, I objectively designed an ICT-led virtual communication platform for information co-production and dissemination with smallholders. Despite widespread smartphone access in households (~ 54 %) of peri-urban farmers, access to weather and climate information via smartphones was rare. During interaction and participatory meetings, I also found younger farmers and local extension officers were using social media for personal communication. They expressed high interest in receiving weather and climate information via social media platforms and smartphone apps. The co-production with smartphone apps and social media could play an increasingly vital role in tailored information exchange and communication. To achieve that I combined ICT tool and training support for farmers and field extension officers during the co-production process to help them improving information uptake and climate-sensitive decision-making.

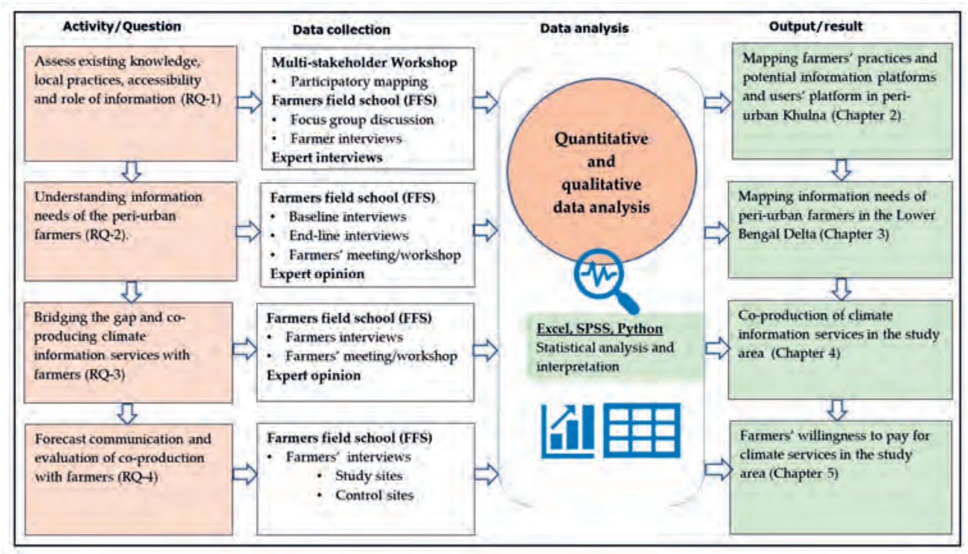

Figure 1.4. Schematic diagram showing the step-wise research activities, data collection, data analysis, and the output connected with the four research questions.

In the first step, I generated open discussions with the Bangladesh Meteorological Department (BMD), Departments of Agricultural Extension (DAE), and farmer field school through organizing a multi-stakeholder workshop. In the workshop, I also invited scientists from the Khulna University, Bangladesh Water Development Board (BWDB), Institute of Water Modelling (IWM), and CIMMYT-Bangladesh who were involved in a similar initiative in Bangladesh. I developed an exploratory research framework followed by the multi-stakeholder workshop to answer the first research question. This combined literature review, secondary and primary data collection, field visits, farmers' interviews, focus group discussion (FGD), and expert interviews. A total of 200 farmer interviews, 4 focus group discussion meetings, and 20 expert interviews were conducted using semi-structured questionnaires and checklists in the selected study sites. Finally, quantitative and qualitative data were analyzed to sketch farmers' local knowledge, practices, accessibility to hydro-information, perceive quality and role of available hydroclimatic information, map the potential information platforms, and forecast users in peri-urban Khulna. I answered the first research question and published a scientific paper at the end of this step presented in Chapter 2.

In the second step, I conducted detailed information needs assessment using a mixed-methods approach (Islam and Hasan, 2016, Islam and Walkerden, 2015, Paul and Islam, 2015, Azorín and Cameron, 2010). Mixed methods were useful for integrating qualitative and qualitative information to synchronize the ground truth better and assess social linkages and access to local public services (Kabir et al., 2016). In this step, I observed that farmers information needs had significantly changed after capacity-building training and frequent interaction with location-specific information services. I realized that climate information needs assessment is not a single-step task. Therefore, I organized two farmer field schools and weekly interactions with information service over a crop period of approximately 16 - 20 weeks. Finally, I conducted an endline needs assessment. The second research question was answered at the end of this step.

In the third step, I co-produced climate information services at FFS to enhance information uptake and farmers' decision-making processes. To bridge gaps between stakeholders, a strong research network was established with sectoral agencies such as the Department of Agricultural Extension, Bangladesh Meteorological Department, CIMMIYT-Bangladesh, Meteoblue (www.meteoblue.com), Khulna University, and farmer field school (FFS) and their experts, followed by the early action multi-stakeholders workshop and iterative interactions. Based on mapping farmers specific needs, in step 1 and step 2; I shared 7-day, 14-day, and seasonal (3-months) visual forecast diagrams at FFS during the face-to-face meeting using paper and a smartphone app. In this step, the co-production of climate information services with farmers led to a better uptake by smallholder farmers. Also, I observed that forecast visualization and communication were essential attributes for the co-production information services followed by training and weekly interactions.

During the co-production process, weekly feedback sessions were conducted using FFS protocol and a semi-structured checklist. The final evaluation process was then conducted applying participatory action research tools, namely personal interviews, and community meetings. The final evaluation assessed the impact of the climate services platform on farmers’ information uptake and decision-making processes for the experimental farmers' agriculture and livelihood strategies. To capture the benefits of co-production, weekly iteration and forecast communication were demonstrated during the Kharif-II crop season of Bangladesh: (mid-July to mid-November). Farmer interactions, early action and stakeholders meetings, training and capacity building activities, etc. were conducted during the study period 2017 - 2020. Based on the farmers' preference, climate information was also communicated before the start of crop season with selected farmer groups (FFS) during the face-to-face meeting using mobile apps and paper-based.

In the final step, I conducted farmers' willingness to pay (WTP) experiment through face-to-face farmers' interviews. A double-bounded dichotomous contingent valuation method was employed to estimate the farmers' willingness to pay (WTP) for participatory climate information services. A similar socio-economic base farming community was selected and studied in the same geographical region as the control site to analyze willingness to pay (WTP) for climate information services in the study area. Research questions 3 and 4 have been answered at the end of this step. To study the implications of participatory co-production, the control farmers group (n=59) was selected at *Mathavanga* peri-urban village in Batiaghata where participants had not received prior training and capacity-building sessions on CIS.

1.5 Thesis Outline

This dissertation is structured into six chapters. Chapter 1 provides a general introduction that includes research background, research objectives, research questions, conceptual framework, case description, and methodology. Chapter 2 represents current practices and the role of information in response to weather and water-related stresses of smallholder farmers in the lower Bengal Delta. Chapter 3 provides an outline of the hydroclimatic information needs of smallholders for agricultural decision-making. Chapter 4 represents the co-production of climatic information services with farmers at farmer field school (FFS) by improving forecast visualization and communication modes. Chapter 5 provides farmers' willingness to pay for climate information services with a comparative analysis between study and control site farmers' groups. Chapter 6 represents general discussion and conclusion, scientific contributions, societal contribution, and outlook for future research.

Chapter 2

Role of Information in Farmers' Response to Weather and Water Related Stresses in the Lower Bengal Delta, Bangladesh

Chapter 2

Role of Information in Farmers' Response to Weather and Water Related Stresses in the Lower Bengal Delta, Bangladesh

Abstract

Farmers in the lower Bengal Delta around the city of Khulna, Bangladesh, are particularly vulnerable to hydroclimatic variability. Phenomena such as heavy rain, drought and salt intrusion increasingly affect their crop production, with far-reaching socio-economic and environmental impacts. Reliable hydroclimatic information service received in a timely manner could help farmers improve their responses to hydroclimatic variability, thus improving their agricultural decision-making. However, significant challenges persist regarding information uptake and the role of information from the available sources. We designed an explorative research framework combining different participatory methods and analysis of climate data. Our aim was to examine three key research questions: (i) what information is currently available to farmers for agricultural practices and decision-making?; (ii) what is the perceived quality of the available hydroclimatic information in response to water and weather related stresses?; (iii) how does the available information influence farmers' decision-making? We found that farmers had access to information from five main sources: informal contacts, formal contacts, education and training programs, traditional media (like television), and modern ICT tools/social media. However, informal contacts, particularly with peer farmers and private input suppliers, were the farmers' main source, in addition to their own previous experiences. Farmers perceived hydroclimatic variability as high and the quality of available hydroclimatic information as poor. They indicated a need for more accurate, time-specific, trusted, and actionable information for improving agricultural decision-making. We conclude that there is high potential and need for hydroclimatic information services tailored for farmers in the study area.

Keywords: hydroclimatic information, agricultural decisions, Bengal Delta, Bangladesh.

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2.1 Introduction

Agriculture is the backbone of the rural economy and livelihoods in Bangladesh. The sector contributes over 15% of the national GDP and generates income and employment for some 43% of the population (Clarke et al., 2015, Kashem et al., 2010). The Lower Bengal Delta, in south-west Bangladesh, is an ecologically rich and highly productive agricultural zone. Farming in the delta, however, is vulnerable to hydroclimatic variability (Huq et al., 2015, Islam and Hasan, 2016, Islam, 2016, Mirza, 2002). Here we understand vulnerability as the state of susceptibility to harm from water and weather-related hazards such as drought, cyclone, heavy or reduced rainfall, flood, etc., and the hydroclimatic variability is the short-term changes or long-term shifts of the water (availability, quality, quantity, and timing, etc.) and weather (temperature, rainfall, wind, etc.) phenomena that have an impact on the overall agricultural production system in a particular geographical area (Adger, 2006, Mondal et al., 2015, Mondal et al., 2013). Agriculture in the delta has become increasingly difficult and risky due to the greater unpredictability of rainfall (Reid et al., 2009, Roy et al., 2009). As a result, farmers increasingly confront problems such as severe waterlogging, salinity intrusion, and drought (Mondal et al., 2013, Rahman et al., 2011, Gain et al., 2007). Moreover, these problems disproportionately affect poor farmers and smallholders (Huq et al., 2015, Mondal et al., 2015, Roy et al., 2009).

The literature suggests that reliable hydroclimatic information received in a timely manner would help farmers improve their responses to hydroclimatic variability, leading to improved agricultural decision-making (Bruno Soares et al., 2018, Templeton et al., 2014, Jones et al., 2000). However, significant challenges persist regarding information uptake and the role of information from the available sources (Islam et al., 2013, Ash et al., 2007, Austen et al., 2002). We approached smallholder farmers and initiated discussions on how they accessed weather and water-related information, such as seasonal weather forecasts, rainfall trends, temperature stresses (hot and cold spells), water and soil salinity, and cyclonic (storm-related) weather emergencies; and what was the perceived quality and role of information found from the different sources in managing hydroclimatic variability.

Indeed, information is acknowledged as a key agricultural input (Tadesse and Bahiigwa, 2015, Aker, 2011). Farmers draw on many sources of information when considering ways to reduce risks and production uncertainties (Aldosari et al., 2017, Mittal and Mehar, 2016, Citroen, 2011). Information on hydroclimatic events is vital for both strategic and tactical decision-making (Haigh et al., 2015). Strategic decisions are those that concern the long term, while tactical decisions concern steps that can be taken in the short to medium term. In both types of decisions, farmers draw on information regarding hydroclimatic conditions (Haigh et al., 2015). For example, seasonal forecasts can improve strategic decisions on, for example, crop types and variety selection, and they can help farmers prepare for weather and water hazards (Webster et al., 2010). Mid-term forecasts (2–4 weeks in advance) can inform farmers' tactical decisions, such as optimization of planting and harvesting dates. Short-term forecasts can help in day-to-day decisions, such as regarding livestock evacuation, crop protection and storage, and management of household and farm assets (Chaudhury et al., 2012) .

In the Lower Bengal Delta, farming communities base agricultural decision-making mainly on traditional practices (Chaudhury et al., 2012). These draw on farmers' own experiences, as well as practical knowledge passed between them and from generation to generation. Bangladesh's Department of Agricultural Extension (DAE) also uses a traditional approach to provide extension information to farmers (Ahmed, 2012). The DAE's main communication platforms are personal and group contacts and traditional media, such as radio, television, and printed manuals. Research shows that the majority of the field extension workers have limited access, usage, knowledge, and capacity for ICT-led extension services (Chowhan and Ghosh, 2020). Besides, farmers also have several limitations to accessing ICT facilities, inadequate information services, and information quality for agricultural decision-making (Rashid and Islam, 2016, Kashem et al., 2010). However, particularly in today's context of accelerating climate change and hydroclimatic variability, these traditional approaches may be insufficient to inform farmers adequately and on time in managing hydroclimatic risks (Kashem et al., 2010, Islam et al., 2013).

Currently, there is a bridge-gap between the hydroclimatic information producer such as the Bangladesh Meteorological Department (BMD), the DAE as a service intermediary, and end-user farmers. The hydroclimatic information services thus required urgent inclusion in the existing agricultural knowledge and information systems for linking farmers and the information producer for shared learning, dissemination, and better-informed agricultural decision-making (Islam et al., 2013). The hydroclimatic information services are still on an emergency basis and for the regional-scale information dissemination that has less usability for local communities (Islam et al., 2013). However, to manage new climate and weather-related risks, farmers need location- and time-specific information and frequent access to local extension officers (Aker, 2011, Tripathi, 2010). Finally, the country's main sources of hydroclimatic information belong to the Bangladesh Meteorological Department (BMD) and the Bangladesh Water Development Board (BWDB), and their reports are hardly disseminated to farmers for agricultural decision-making purposes (Islam et al., 2013, Roy and Alam, 2020).

A major challenge, therefore, is to find ways to get hydroclimatic information to local farmers in formats that are useful to support their decision-making. New kinds of information support, technology, organization and expertise are needed to help the vulnerable communities (Rarieya and Fortun, 2010). Another key challenge is to tailor hydroclimatic information for local farmers and get it to these farmers enough in advance that it can inform strategic and tactical decisions on agricultural practices. In this regard, co-production can be an ideal approach (Naab et al., 2019, Christel et al., 2018).

Indeed, co-production studies are currently narrowly framed (Bremer et al., 2019); and several challenges exist in the socio-economic, socio-political, and cultural contexts (Golding et al., 2017, Kundzewicz et al., 2017) Thus, to effectively tailor and communicate information to farmers in a local context, a detailed understanding of farming practices is needed (Vogel and O'Brien, 2006). Vaughan and Dessai (2014) found a mismatch between information needs and information being provided to the sectoral users. Knowledge is required, for instance, on the time horizon in which key decisions are made (Finucane et al., 2013). In addition, it is important to know what information sources are now available to farmers, and how farmers perceive the quality of information from these sources, as well as their perception of the value of existing platforms in providing useful information.

With this in mind, we posed three research questions centered on hydroclimatic information services for farmers in the delta: (i) What information is currently available to farmers to inform their agricultural practices and decision-making? (ii) To what extent do farmers perceive the available hydroclimatic information as helpful in responding to water- and weather-related stresses? (iii) How has the available information influenced farmers' decision-making? To answer these questions, we designed an exploratory research framework combining field visits, farmer interviews, focus group discussions, and expert interviews with analysis of climate data. Our aim was to map and understand the information sources available in the study area, to identify the limitations of the existing sources, and to suggest ways to better design information for increased uptake at the local level.

2. 2 Materials and Methods

2.2.1 Description of the study sites

The Bengal Delta, also known as the Ganges-Brahmaputra-Meghna (GBM) Delta, located in the northern shores of the Bay of Bengal, is one of the populous deltas of the world (Rahman et al., 2020, Kida and Yamazaki, 2020). This delta has a unique ecosystem characteristic comprising the three mighty river systems (Ganges-Brahmaputra-Meghna) enclosed by the terrestrial, aquatic, and marine ecosystems (Akter et al., 2020). The city Khulna is located in the lower part of the Bengal Delta frequently stressed by tidal surge related inundation, salinity intrusion, tropical cyclone, and hydroclimatic variabilities (Akter et al., 2020, Sherin et al., 2020, Hasan et al., 2020, Al Masud et al., 2020, Datta et al., 2020). The city is highly dependent on peri-urban agriculture for its food supply. Khulna is also a regional food supply hub, though this region of Bangladesh is particularly vulnerable to the effects of climate change. The city's importance in regional food supply and the vulnerability of its farming communities to climate change impacts were key reasons for its selection for this study. Indeed, Khulna is a zone of multiple vulnerabilities as well as opportunities (Huq et al., 2015, Afroz and Alam, 2013) [3,49]. It is the third largest (64.78 km2) metropolitan area in Bangladesh. Khulna district has 9 upazilas (sub-districts) and about 2.3 million inhabitants (BBS, 2013).

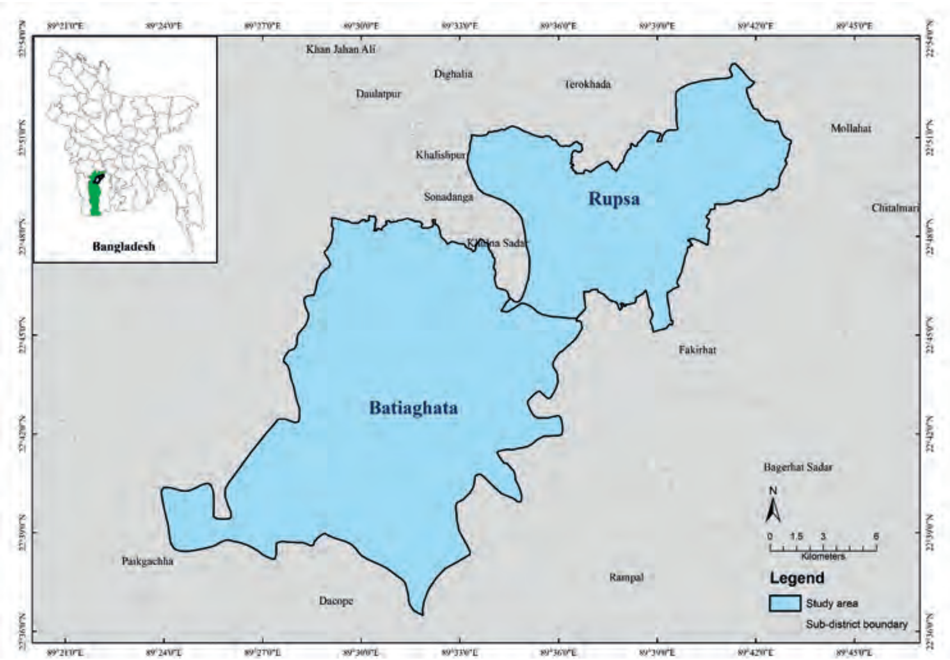

Figure 2.1. Map showing location of the study area in Khulna, Bangladesh. Khulna is indicated on the inset map in green. The two study sites, Batiaghata and Rupsa, are in light blue. The city of Khulna is located between Batiaghata and Rupsa.

The climate in Khulna is subtropical warm and humid, with four distinct seasons: (i) dry winter (December to February), (ii) hot pre-monsoon summer (March to May), (iii) rainy monsoon (June to September) and (iv) post-monsoon autumn (October to November) (Shahid, 2010).

We obtained climatological data from the Bangladesh Meteorological Department (BMD). According to this data, over the 1948–2018 period the average annual rainfall was 1752.3 mm and the mean annual air temperature was 26.7 °C (see Supplementary Material 2A). The average monthly minimum and maximum temperatures were 21.9 and 31.3 °C, respectively. January was the coldest month, with a mean minimum temperature of 12.9 °C. April was the warmest month, with a mean maximum temperature of 34.9 °C, with an average annual rainfall anomaly of ± 48.6% to 35.5% from 1981 to 2014. According to the literature, some 80% of precipitation occurs in the monsoon season from May to September (Mondol et al., 2018b, Shahid, 2010, Ahasan et al., 2010). However, our data for 1948–2018 indicate that the monsoon season extended from May to October, with some 90% of total annual rainfall occurring during these months (see Supplementary Material 2A). The highest and lowest rainfall quantities were found in July and December, with monthly averages of 327.6 mm and 4.5 mm, respectively. Due to the abundance of rainfall in the region, the area offers excellent opportunities for rainfed agriculture (MoA and FAO, 2013).

For our study, we selected two sub-districts: Batiaghata (~248 km2) and Rupsa (~120 km2) (Figure 2.1). Major crops grown here were paddy, jute, sesame and vegetables, with small-scale aquaculture-agriculture also observed year-round. Farmers grew various short-term crops and vegetables as well, such as beans, gourds, eggplants and tomatoes, in integrated aquaculture-agriculture farming systems. Integrated farming systems have been found to provide greater economic returns than paddy or vegetable monocrops. Additionally, Talukder and Saifuzzaman (2016) found that an integrated farming system consisting of paddy, vegetables and aquaculture was more resilient to recurrent hydroclimatic variability.

2.3 Site Selection, Data Collection and Analysis

This study used an explorative research framework combining desk research, secondary data collection, field visits, focus groups and expert interviews (Figure 2.2). A mixed-method approach for this study allows us to collect information and triangulation through different participatory tools and approaches.

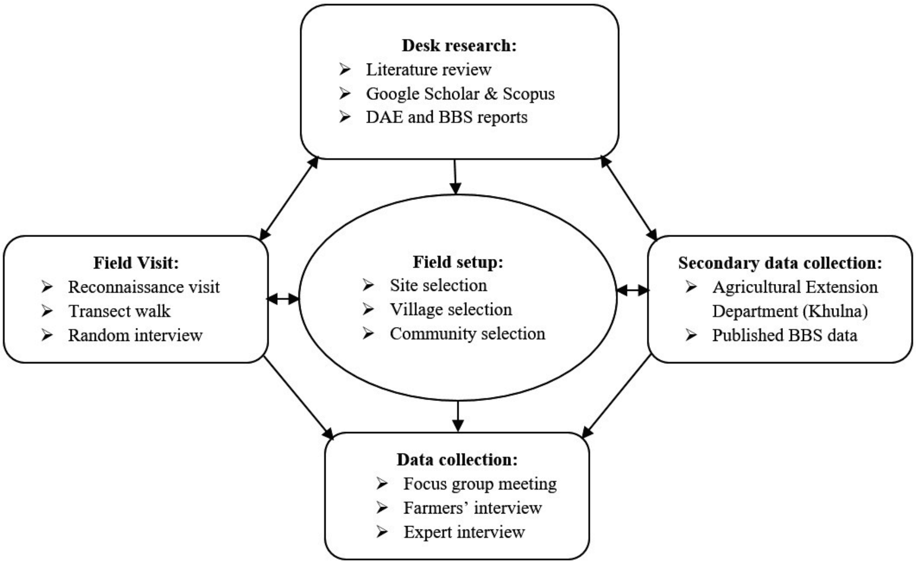

Figure 2.2. Study and data collection framework.

We focused on six peri-urban villages within Rupsa and Batiaghata sub-districts, where we carried out 200 farmer interviews, 4 focus group discussions and 20 expert interviews from August 2017 to May 2018. Questionnaires (Supplementary Material 2B) and checklists (Supplementary Material 2C and Supplementary Material 2D) guided primary data collection through the interviews and focus groups. Table 2.1 describes the stakeholders engaged and methods of data collection applied for each. Secondary data were collected from documentary sources: journals, reports from the Bangladesh Bureau of Statistics (BBS) and unpublished documents from DAE district and sub-district offices regarding crops, population and livelihood characteristics of farm households in the study area.

Three of the surveyed villages—Sreefaltala, Domra and Peyara—were located in Rupsa, and the remaining three villages—Jharbhanga, Raingamari and Sanchibunia—were in Batiaghata. In Bangladesh, the lowest administrative jurisdiction of government is called a “union”. Unions are divided into agricultural blocks, each of which has its own Sub-Assistant Agriculture Officer (SAAO). The SAAO, working under the DAE, provides extension services to some 2000 farm households. All of the selected villages exhibited peri-urban characteristics; that is, they were located in close proximity to the Khulna metropolitan area, and were highly interdependent and interconnected with the city.

Table 2.1. Stakeholders and Methods of Primary Data Collection.

Stakeholders	Participants	Methods/Tools	Reason for Engagement
Local farmers	Men (138) Women (62)	- Field visits - Transect walk - Farmer interviews - Focus group discussions	Source of primary data on demography, agricultural practices, agricultural information needs and future interest in hydroclimatic information services.
Extension officer (district level)	- Deputy Director (1) - District Training Officer (1)	- Consultation meeting - Expert interviews	In charge of extension services at the district level. The district training officer is in charge of agricultural training at the district level.
Extension officer (sub-district level)	- Upazila Agriculture Officer (2) - Upazila Agriculture Extension Officer (3)	- Expert interviews - Focus group discussion	Responsible for providing extension services at the sub-district level.
Extension officer (field level)	- Sub-Assistant Agriculture Officer (4)	- Expert interviews - Focus group discussion	Provides field-level extension services to farmers, usually grouped as an agricultural block.
AIS officer (regional level)	- Regional Farm Broadcasting Officer (1)	- Expert interview	Provides agricultural information at the regional level using traditional and ICT platforms.
Met officer (district level)	- Assistant meteorologist (1) - Met assistant (1)	- Expert interviews	Collects daily and hourly data on local weather parameters.
Input dealers (local level)	- Local input dealers and retailor (4)	- Expert interviews	Sells inputs to local farmers and provides crop advisory services.
Researchers	- Agrotechnology faculty, Khulna University (2)	- Expert interviews	Involved in agricultural extension research for more than 10 years.
Total	- Farmers (200) - Experts (20)		

After site selection, data on information use in agricultural decision-making were gathered through focus group discussions and farmer and expert interviews, guided by checklists and questionnaires. Focus group discussions. Four focus group discussions were held in Rupsa and Batiaghata. Two meetings were arranged in each sub-district. All the meetings were guided by the same checklist (Supplementary Material 2C), covering four key topics: (i) current cropping practices, (ii) access to weather and water related information for agricultural decision-making, (iii) traditional knowledge and farming practices and (iv) measures to address weather and water challenges. The focus groups also touched upon key agricultural decisions and time horizons for taking specific decisions related to crops and livelihoods. The focus group meetings were conducted in the farmers' villages in October and November 2017 and involved 10 and 16 participants, respectively, in Rupsa and Batiaghata. Two research assistants took notes during these meetings. Qualitative data from the meetings were summarized and entered into Excel for further analysis and interpretation.

2.3.1 Farmer interviews

Two-hundred farmers were interviewed. This sample size was determined following Berenson and Levine (1992) to obtain a 95% confidence level based on the total population of households (858). In total, 62 households were selected from Batiaghata and 138 from Rupsa. Table 2.2 presents key data on the interviewed farmers. With the interviews, we sought to obtain a quantitative overview of the farming communities and farming practices, including farmers' access to and the quality of information sources and their interest in and need for expanded information services for agricultural decision-making. We designed a semi-structured questionnaire to guide the farmer interviews (Supplementary Material 2B). These were informed by consultations with experts, field visits and random farmer interviews carried out ahead of time. Furthermore, the questionnaire was pre-tested with 10 randomly selected farmers at both sites. Based on the pre-test, we made minor changes to the questionnaire. Farmer interviews were conducted using the open-access online interview tool KoBoToolbox (www.kobotoolbox.org). Two female master's degree students conducted the interviews. In Bangladeshi society, women have easier access to unknown households than men. It took two months to complete the interviews. Simple random sampling was used to select interviewees. Finally, SPSS Statistics 20 software was used to analyze and interpret the quantitative data obtained.

2.3.2 Expert interviews

We interviewed 20 experts using open-ended questionnaires (Supplementary Material 2D, see list of experts in Table 2.1). Interviews focused on the extension services currently provided, limitations of existing information and extension services, need for hydroclimatic information for agricultural decision-making, and current agricultural decision-making practices of farmers in Khulna. Several more specific topics were also discussed with the experts, such as how farmers dealt with hydroclimatic information and what role available information sources and quality played in agricultural decision-making. Finally, the interview results were summarized and entered into Excel for analysis and interpretation.

2.3 Results

2.3.1 Characteristics of farmers

In this study, 69% of the 200 respondent farmers were from Rupsa and 31% were from Batiaghata. The majority of the farmers were sharecroppers (74%), and about a third (31%) were functionally landless (~0.02 ha) (Table 2.2). Some 26% of the farmers were illiterate. Only 10% were in the 18–25 age range, indicating that few young men and women were involved in agriculture in the study area. However, a significant number of retired government officials were involved in agriculture at the study sites. All of the interviewed farmers expressed an interest in hydroclimatic information to inform agricultural practices, and 91% expressed interest in a mobile phone application for receiving hydroclimatic information.

2.3.2 Access to mobile phones

Despite relatively widespread mobile phone usage in the study area, access to agriculture-related information via mobile phones was rare. Though 85% of the sampled farmers did use a personal mobile phone, most of these (74%) indicated that they did not use a mobile phone to access agricultural information. Farmers reported a number of reasons for the limited usage of mobile phones in agriculture. Major reasons were lack of ICT knowledge (81%), incompatible format and language (50%), lack of a smartphone (37%) and economic reasons (17%). Half of the farmers (54%) had access to a smartphone in their household. Younger farmers (10% of the sample) between the ages 18–25 years and middle-aged farmers between the ages 26-60 years (75% of the sample) were interested in a mobile phone application for receiving agricultural information. However, the illiterate farmers (9% of the sample) and farmers older than 60 (16% of the sample) expressed a preference for receiving agricultural information through face-to-face sources. Some of these older farmers (5% of the sample) observed that in-person communication was more reliable, since people could tell lies over mobile phones, especially regarding input and market prices.

Table 2.2. Descriptive Statistics of the Respondents' Households, Rupsa and Batiaghata Sub-Districts, Khulna.

Variables	**N = 200**	**%**	**Variables**	**N = 200**	**%**
			Land ownership		
Rupsa	138	69	Landless (0.02 ha)	62	31
Batiaghata	62	31	Marginal (0.02-0.2 ha)	55	28
			Small (0.2-1.0 ha)	58	29
			Medium (1.0-3.0 ha)	20	10
			Large (>3.0 ha)	5	3

Gender			House type		
Male	138	69	Kacha (local materials)	87	44
Female	62	31	Pucca (brick-concrete)	66	33
			Semi-pucca (brick-tin)	46	23
Age (years)			Mobile phone access		
18–25	20	10	Normal mobile phone	171	85
26–40	72	36	Smartphone	109	54
41–60	77	39	Mobile used in agriculture	52	26
Above 60	31	16	Interested in mobile app	182	91
Education			Drinking water source		
Illiterate	52	26	Tubewell (>100m)	145	72
Primary ed.	56	28	Tubewell (<100m)	40	20
Secondary ed.	44	22	Pipe supply	6	3
HSC and above	48	24	Other (multiple)	9	5

2.3.3 Crop cultivation in peri-urban Khulna

Agricultural practices differ by season. The agricultural calendar in Khulna is constituted by three crop seasons: Kharif-I (pre-monsoon), Kharif-II (monsoon), and rabi (winter). Kharif-I (mid-March to mid-June) is a transitional minor crop season. The two major crop seasons are Kharif-II and rabi. Table 2.3 and Figure 2.3 present the crops cultivated in the study areas during these seasons. Paddy was the dominant crop of the majority of farmers. During Kharif-II (mid-June to mid-November), it was cultivated by 71% of the farmers sampled and during rabi (mid-November to mid-March) by about 33%. Focus group participants (n = 52) and agriculture extension experts (n = 20, see Table 2.1) reported that paddy was grown for household food security. However, they also reported that there had been a major shift in cropping practices over the past few decades, in response to hydroclimatic variability. Paddy farmers were increasingly growing different short-term crops and vegetables, such as gourds, beans, cucumbers, tomatoes, and watermelons, alongside small-scale aquaculture. Agriculture extension officers in both Batiaghata and Rupsa confirmed the emergence of integrated farming systems spanning the three crop seasons. We also found a trend of increasing rainfall in the study area. This likely played a role in promoting the cultivation of short-term vegetables integrated with aquaculture (see Supplementary Material 2A).

Extension officers observed that 10 to 20 years ago, farmers cultivated the local paddy varieties aus and aman. However, after the introduction of improved paddy varieties (upsi) and high yielding varieties (HYV), farmers lost interest in aus paddy cultivation in Kharif-I (mid-March to mid-June). At the time of our survey, the majority of farmers (71%) cultivated aman paddy only during Kharif-II (see Table 2.

2). Some farmers cultivated paddy with vegetables (18%), while others mixed vegetables with aquaculture (6%) or cultivated only vegetables (3%) during Kharif-II. A few farmers (3%) said they left their land fallow during Kharif-II, due to waterlogging and flooding.

Rabi is the water-scarce dry crop season. Boro paddy (33%) and winter vegetables (26%) were the main rabi crops in the study area. Major vegetables grown during this season were cabbage, cauliflower, eggplant, spinach, beans, red amaranth, radish, pumpkin, and tomato. Groundwater and surface water salinity increased during rabi. Farmers with irrigation facilities (33% of the sample) cultivated boro paddy during this time. Those with limited irrigation (26%) tended to cultivate short-term vegetables during rabi. Farmers without irrigation water left their lands fallow during rabi and Kharif-I. Of the sampled farmers, 28% left their lands fallow in rabi and 47% did so in Kharif-I. In rabi, about 8% of the sampled farmers cultivated paddy with vegetables, and 3% of farmers cultivated sesame as a short-term crop. Very few farmers mixed aquaculture with vegetable cultivation (0.5% of our sample) or vegetables with another short-term crop (2.5%) during rabi. However, in the low-lying *beel* areas on the outskirts of Khulna, aquaculture, and aquaculture mixed with vegetables were popular year-round, practiced by 12% of the farmers surveyed.

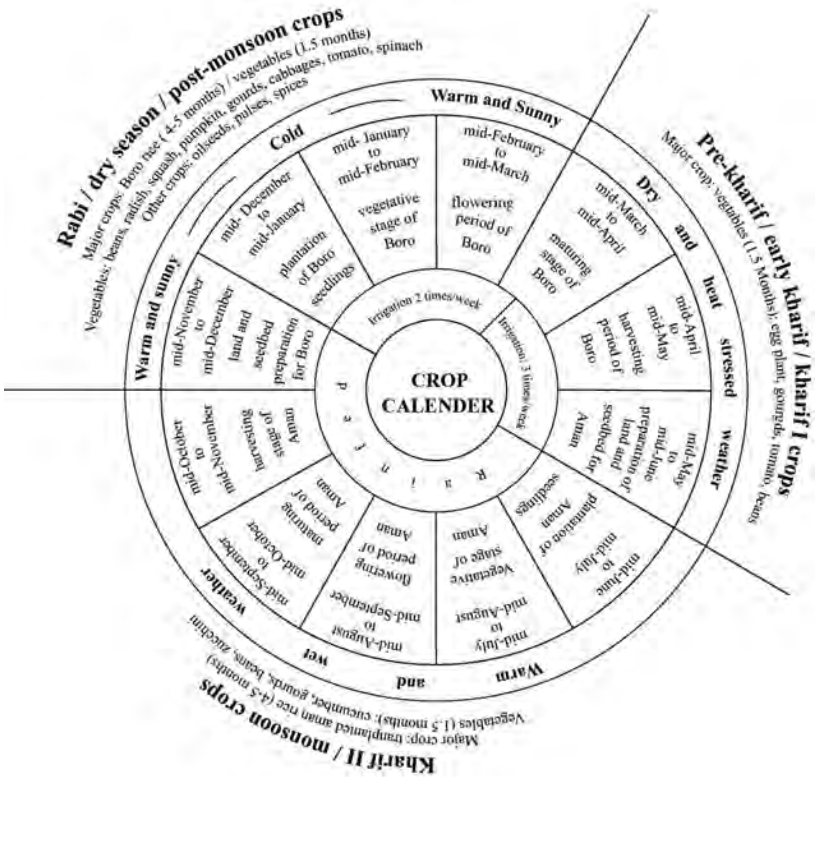

Figure 2.3. Crop calendar of peri-urban Khulna constructed based on group meetings and individual interviews.

Table 2.3. Cultivation practices among peri-urban farmers in Khulna during the three crop seasons

Cultivation practices	**Khariff-I (mid-Mar to mid-June)**		**Khariff-II (mid-June to mid-November**		**Rabi (mid-November to mid-March)**	
	Frequency	%	Frequency	%	Frequency	%
Paddy	47	24	141	71	66	33
Paddy and other crop	4	2	35	18	15	8
Vegetables	26	13	6	3	51	26
Vegetables and other crop	17	9	-		5	3
Aquaculture and Vegetables	10	5	12	6	1	1
Sesame and pulses	2	1	-		6	3
Fallow	94	47	6	3	56	28
Total (N = 200 interviews)	200	100	200	100	200	100

Note: due to rounding, some of the categories total 101%.

2.3.4 Agricultural information sources and their value to farmers

Agricultural information here refers broadly to information that plays a potential role in agricultural decision-making, such as seasonal weather forecasts, water availability, input prices and availability, crop selection, disease control, and market prices. The farmers and experts interviewed or participating in focus group sessions for this research identified 18 agricultural information sources used by farmers in the study area. We classified these into five broad categories: informal contacts, formal contacts, education and training programs, traditional mass media, and modern ICT tools/social media (Table 2.4).

We explored the value that farmers attached to each of these sources, and reasons for their preferences, again based on findings from the interviews and focus groups. First, from the farmer interviews, we determined the percentages of respondents favoring a particular information source. Then, we derived the value farmers attached to that source by the proportion of respondents favoring it. These values were subdivided into five categories: very high value (more than 80% of the respondents favored it), high value (60–80% of respondents favored it), medium value (40–60%), low value (20–40%) and very low value (<20%). We discerned reasons why the various sources were perceived as valuable (or not) from comments made by farmers in the interviews and focus groups. For example, 66% of the farmers interviewed (i.e., between 60–80%) indicated valuing information obtained from peers, while 100% of the interviewed farmers (i.e., >80%) indicated valuing information received from input dealers. These sources were thus determined to have a high and very high value, respectively, to local farmers. The farmers attached very low value (i.e., <20%) to information available from ICT platforms, such as mobile phones, the internet, and social media. Below, we elaborate on these different types of information in more detail.

Informal contacts. This is the traditional way farmers communicate and access information. It is highly social, often requiring no extra time or added expenditure. Farmers said that personal experience gained over years, and consultation with peers, brought new insights regarding land preparation, crop and variety selection, water availability, seasonal weather, and emergencies. Our respondents had 20 years of farming experience on average. Therefore, the majority had vast personal experience to draw on for agricultural decision-making. In addition to exchanges with peers, farmers gained information via informal contacts with trusted input dealers and local retailers, particularly regarding input prices, new crop varieties, disease control, cultivation methods, and crop production.

While some farmers indicated obtaining information from extension officers, in practice, the majority went directly to trusted input dealers rather than to the extension office. According to one farmer interviewed, “Input dealers are always available and accessible, and they have all kinds of information for agricultural decision-making.” Communication with input dealers was considered easy, efficient, and well-aligned with farmers’ information needs and time schedules.

Formal contacts. The farmers interviewed considered formal information sources to be of medium (40–60%) to very low (<20%) value. The medium value indicates that 40–60% of farmers favored the information source, and the very low value indicates that <20% of farmers favored the source. The DAE, via the SAAOs, was the main formal source of information, for example, regarding seasonal crop cultivation, disease control, new technologies, organic agriculture, soil health, and government subsidies for farmers. Yet, each SAAO was responsible for providing information to some 2000 farmers and did this mainly through individual and group-based interactions. It was thus difficult to get sufficient information to all, within the needed timeframe. From the farmers’ perspective, too, it was difficult to obtain information from their SAAO or even from the DAE office, as many farmers (79%) had secondary off-farm occupations during working hours. These prevented them from being able to access information through formal contacts during local extension officers working hours.

The Agriculture Information Service (AIS) is a governmental organization under the Ministry of Agriculture responsible for providing agriculture-related information to farmers and other interested stakeholders. However, none of the farmers participating in this research had used information from AIS. AIS employed both traditional media (mainly radio and television) and ICT-based platforms (the internet and social media) to disseminate information on agricultural production, technology, and innovation.

Non-governmental organizations (NGOs) were occasionally active in providing agricultural information. Overall, however, farmers attached little value to information accessed this way. Similarly, the Union Digital Centre (UDC), a formal government entity established to provide information services at the union level, had seldom been accessed by farmers for agricultural information.

Education and training programs. Education and training were mostly provided by the DAE and development partners. Farmer Field Schools (FFS) was an approach often used by the DAE for group-based education and training (Kabir and Rainis, 2015, Bijlmakers and Islam, 2007). Topics addressed at FFS events included seasonal crops and cultivation methods, disease outbreak awareness, new crops, variety advice, and government subsidies. The interviewed farmers in Batiaghata attached high value to the information they gained from DAE FFS events. However, we found no farmers with FFS experience in Rupsa. This is because FFS events were typically conducted under specific government or non-government projects, meaning that they were unavailable outside the project localities. The DAE expressed the aim of its FFS events as to build farmer capacity, enabling farmers to take informed decisions in relation to crops and livelihoods.

Besides FFS events, the DAE also organized group discussions, yard meetings, and field demonstrations for education, training, and awareness-raising. Farmers indicated that these programs had high to medium value in terms of agricultural information provision. At the time of this research, weather information was a key focus of DAE farmer training and awareness-raising. It aimed to help farmers better adapt to hydroclimatic variability and livelihood vulnerabilities. Leaflets and brochures were being distributed as part of these efforts. Some 40–60% of the farmers interviewed had received these DAE leaflets or brochures. They attached medium value to them as an information source (Table 2.4).

Traditional mass media. Television, radio, and newspapers remained an important source of agricultural information among the farmers interviewed. Television, particularly, was a preferred medium. Some 69% of the interviewed farmers attached high value to agricultural information obtained from television. However, few of the farmers in our sample used newspapers (9%), and just a fifth used radio (20%) as a source of agricultural information. Reading newspapers was not a common practice among farmers around Khulna. This may be due to lack of access or the high cost of newspapers, alongside the ready availability of mobile phones, television, and the internet. Farmers participating in the focus groups said that radio was practically extinct as a source of agricultural information. However, a few aged farmers in the Batiaghata group indicated that during severe weather events they got weather updates from both radio and television. Since 1983, the television magazine shows Hridoye Mati O Manush has been one of Bangladesh's most popular programs on agriculture. All of the farmers participating in the focus group sessions commented on the value of this program for gaining information about new crops, cultivation practices, technologies, and innovation in agriculture. However, in practice, all of the farmers said they still based their decisions mainly on traditional information and planned farming activities in line with their previous experiences and tradition. Thus, information from these media seemed to hardly influence farmers' decision-making.

Modern ICT tools and social media. ICT applications in agriculture began to emerge in Bangladesh during the 1980s. Yet, the farmers participating in this research attached little value to them. Mobile phone calls were valued by 26% of the interviewed farmers as an information source for agriculture, with smartphone applications valued by 4% and social media by 3%. Traditional sources were much more highly valued, particularly personal experience (valued by all of the interviewed farmers), consultation with peers (valued by 66%), and information from input dealers (valued by 100%). Almost all organizations active in the agricultural sector had modern ICT platforms, including websites, call centers, smartphone applications, and social media platforms, which they used to share and disseminate agricultural information. However, farmers attached little value to these for agricultural decision-making (see Table 2.4).

Farmers and experts expressed four key limitations to information uptake from ICT platforms: lack of location- and time-specific information, lack of accessibility, lack of awareness, and lack of capacity. For example, in June 2012, AIS launched a mobile phone-based information platform called the Krishi Call Centre. However, none of our respondents used that platform. Other ICT platforms, both government- and non-government-run were similarly disregarded by farmers, who noted that they had little or no value for their decision-making. Perhaps this is because these platforms were created in a mostly non-participatory and top-down manner. Interaction with farmers in their development was limited. Moreover, information communicated via these platforms tended to be out of date. Facebook was a popular social media platform in the study area, but it was not being used to share agricultural information. Training, capacity, participation, and partnership efforts between information producers and users would be required to improve the overall local impact of the ICT platforms in the study area.

Table 2.4. Available sources of agriculture-related information and the value farmers attached to each for agricultural decision-making in peri-urban Khulna. Value categories are as follows: “very high”, “high”, “medium”, “low” and “very low”. These reflect, respectively, the percentages >80%, 60–80%, 40–60%, 20–40%, and <20% of farmers favoring that source. Data were drawn from interview results and focus group discussions.

Main Information sources		**Current Value to Farmers (N=200)**	**Reason the Source Was or Was Not Valuable to Farmers**
Informal Contacts	Personal experiences	Very high (100%)	- Tried and true nature of personal expertise and skills - Experience with same crops at the same locality
	Consultation with peer farmers	High (66%)	- Easy to communicate - Personal kinship and friendship - Always available and accessible
	Input dealers, retailers, and company representatives	Very high (100%)	- Easy to communicate - Personal kinship ties - Dependence on loans for inputs - Warranty on input services - Proactive information services - Feedback mechanisms exist
Formal Contacts	DAE	Medium (44%)	- Difficult to communicate - Time-consuming process - Time schedules do not match
	AIS/AICC	Very low (2%)	- Difficult to communicate - Limited access for farmers - Traditional media dependent - Limited service coverage - No feedback and limited interaction on service provision
	Union Digital Centre (UDC)	Very low (5%)	- Limited expertise in agriculture - Time consuming process

			- Hardly useful to farmers
	NGOs	Very low (9%)	- Limited service delivery - Project and beneficiary based - Availability for limited periods
Education and Training	Farmer field schools	High (66%)	- Easy to communicate - Group learning and sharing - Technical knowledge improved - Long-term skills learned
	Individual education and training	High (60%)	- Training on contemporary issues - Builds capacity on new technologies for crop production
	Group meetings, field days, workshops and conferences	High (60%)	- Easy to communicate - Shared learning process - No extra time needed - Personal kinship and social assets
	Extension materials and leaflets	Medium (44%)	- Easy to communicate - Advanced information - Free of cost - Builds knowledge and awareness
	Fairs and exhibitions	Medium (40%)	- Face-to-face communication - Fun to see others
Traditional Media	Newspapers	Very low (9%)	- Limited access at the village level - Limited reading culture - Some farmers illiterate - Limited information on agriculture
	Radio	Very low (18%)	- Very limited use by farmers - Traditional technology - Information not location-specific - Information not time-specific
	Television	High (69%)	- Programme formats easy to follow - Live programs - News programs share innovation - Many television channels
ICT/Social Media	Mobile calls, direct messages, multimedia messages	Very low (16%)	- Information not location-specific - Unnecessary messages from the operator - Lack of education and awareness - No feedback mechanism

		exists
Mobile phone applications	Very low (4%)	- Lack of ICT knowledge - Lack of smartphone access - Top-down/not informed - Lack of awareness of information - No feedback mechanism exists
The internet, websites, E-Krishi, E-Kiosk and social media	Very low (3%)	- Lack of ICT knowledge - Lack of smartphone - Lack of education and training - High cost of internet facilities - No feedback mechanism exists

2.3.5 Hydroclimatic information availability and quality

Farming communities around Khulna are highly vulnerable to hydroclimatic variability. Major changes have been observed in, for example, monsoon rainfall patterns; river discharges and tidal characteristics; salinity intrusion in soils; groundwater and surface water; temperature stresses (droughts and hot and cold spells); and weather emergencies such as thunderstorms, hailstorms, and cyclones. However, the extension experts (n=7) noted a lack of active information provision to farmers on these topics. The BMD and BWDB were the two main government organizations providing hydroclimatic information at the national, regional, and local levels. However, both farmers and extension experts indicated the inadequacy of the BMD and BWDB information for use and understanding by farmers. Local BMD officials said that BMD and BWDB divisional and local offices had no obligation to provide information services to farmers. The BMD collected weather information, such as temperatures, rainfall, wind speeds, wind directions, and hours of sunshine, from local weather stations and transmitted it to its national headquarters. Likewise, BWDB collected water information, such as river discharge, water levels, and salinity, through local stations and sent it on to their national headquarters. The collected information was then disseminated at the national level through traditional and ICT platforms. In this process intermediaries and end-users had no role in designing and delivering the information. Similarly, BWDB's Flood Forecasting and Warning Centre (FFWC) provided flood forecasts and warnings pertaining to all major rivers, but with limited access, comprehensibility, and actionability at the community and individual farmer levels.

We analyzed farmers' information access behavior particularly for hydroclimatic information from different sources. Results show that 69% of the 200 farmers in our sample obtained weather information from television, and 67% from peers (Figure 2.4a). About 22% of the farmers also inquired at their extension field offices regarding upcoming weather hazards, and 20% of farmers listened to the radio for weather updates only during bad or extreme weather. Although about 85% of the farmers in our sample had mobile phone access, only 15% used mobile phones to access hydroclimatic information, either from peer farmers or from the agricultural extension department. Very few farmers (9%) read the newspaper for weather updates, and only 8% said they were experienced in understanding local weather phenomena. Nevertheless, during emergency weather events, farmers did obtain information from multiple sources, including the agriculture extension department, television and radio, local and national newspapers, input dealers, NGOs, and community organizations.

According to the farmers in our sample, the overall quality of the hydroclimatic information available was unsatisfactory. For example, it was not sufficiently location- and time-specific to help them to make specific decisions. The farmers in the focus groups, too, said that they could not rely much on the hydroclimatic information broadcast via radio and television. They added that only in about 5–10% of instances was the information somewhat applicable to their location. Farmers also noted the lack of crop advisory services related to hydroclimatic forecasts, which often came late. More than 60% of the respondents said that the existing weather information services were poor or very poor at the local level and of insufficient quality to aid in agricultural decision-making (Figure 4b).

Some 35% of the farmers indicated that the present information quality was acceptable, especially during emergency weather events. They observed that emergency forecasts on cyclones, storm surges, and floods were disseminated proactively by governmental, non-governmental, and community organizations. Based on that information, farmers could sometimes prepare in advance for extreme weather events. Farmers and experts noted that field crops were difficult to protect during extreme weather events. However, if sufficient information was available in advance, harvested and mature field crops, livestock, fishponds, and household and farm assets could be protected from major damage.

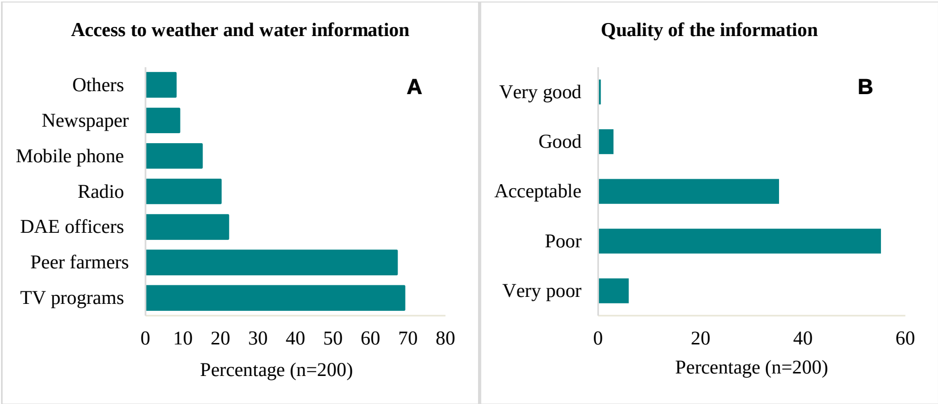

Figure 2.4. Farmers' access to hydroclimatic information sources and their perception of the quality of information from those sources. Figure 2.4A shows farmers' access to hydroclimatic information from different sources, and Figure 2.4B shows an overall judgment about the hydroclimatic information quality found from all sources.

2.3.6 How farmers used available information in decision-making

Farming communities in Khulna considered hydro-climate hazards "God-given phenomena". Thus, their information-seeking behavior for climate events was limited, and their decision-making was driven mainly by tradition and personal experience. However, within our sample, young farmers (10%), educated farmers (46%) and farmers with diversified operations (about 17%, 24%, and 14%; see Table 2.4) reported using multiple information sources, especially for crop selection, planting times, fertilizer and pesticide application, irrigation management, harvest planning and marketing (Frisvold and Murugesan, 2013). Consideration of hydroclimatic information for crop management decisions varied significantly between the farmer categories. For example, smallholder paddy farmers took key decisions based mainly on their personal experience and traditional practices. But farmers with integrated operations were more apt to try to hone their decisions in consultation with peers and advice from input dealers and extension officers.

The focus group discussions confirmed that farmer age, gender, education, farm type, farm size, personal beliefs, and risk-aversion were important characteristics affecting the amount of information consulted in decision-making. For example, young, educated male farmers frequently communicated with the field agriculture officers and input dealers for informed decision-making. Whereas female farmers hardly communicated with the field agriculture officers and input dealers for agricultural decision-making. This may be because women farmers were less engaged in field crop cultivation. The majority based their agricultural decisions on their own previous experiences and advice from peer farmers nearby. Routine use of hydroclimatic information was not commonplace among the sampled farmers. It was particularly uncommon among smallholders (79% of the sample); they often also had off-farm income sources in or around the city.

Five key determinants of cropping plan decision-making were identified: agronomic considerations, economic considerations, resource-related considerations, farmland-related considerations, and climatic considerations. In our study area, we identified two additional determinants of agricultural decision-making: individual considerations and input support from government and non-governmental agencies. Table 2.5 presents the expanded list of key determinants of cropping plan decision-making. Smallholder farmers around Khulna grew paddy due to individual considerations: they wanted to ensure their household's food security. As one farmer said, "If we have rice at home, we are free from the stress of buying rice at the market." Furthermore, a good yield in the previous season informed farmers' cropping decisions in the next seasons. Due to the increasing frequency of hydroclimatic events, farmers indicated that they now preferred short-term, salt- and drought-tolerant varieties. All farmers perceived hydroclimatic variability as high in Khulna, and farmers always sought to make better decisions based on their growing experience and perception of hydroclimatic risks and uncertainties.

Figure 2.5 presents perceptions of hydroclimatic variability among the sampled farmers. Additionally, the farmer focus groups sketched 14 major farming decision areas: crop selection, land preparation, variety selection, seeding, hiring labor, transplantation, weeding, irrigation, fertilizer application, pesticide application, harvesting, processing and storage, seed preservation, and marketing. These represent key tactical, or medium-term decisions, that can be aided by multiple types of hydroclimatic information. For example, farmers might decide to purchase particular seeds, inputs, or varieties based on hydroclimatic forecasts. Adaptive decisions, in contrast, refer to long-term strategic decisions aimed at adjusting to hydroclimatic variability and change. For example, paddy farmers at Batiaghata had switched from paddy to watermelon, because of the scarcity of irrigation water and problems of salinity intrusion during the boro paddy season. Decisions such as these drew on information from different sources and farmers' risk perceptions drawing on traditional knowledge and experience.

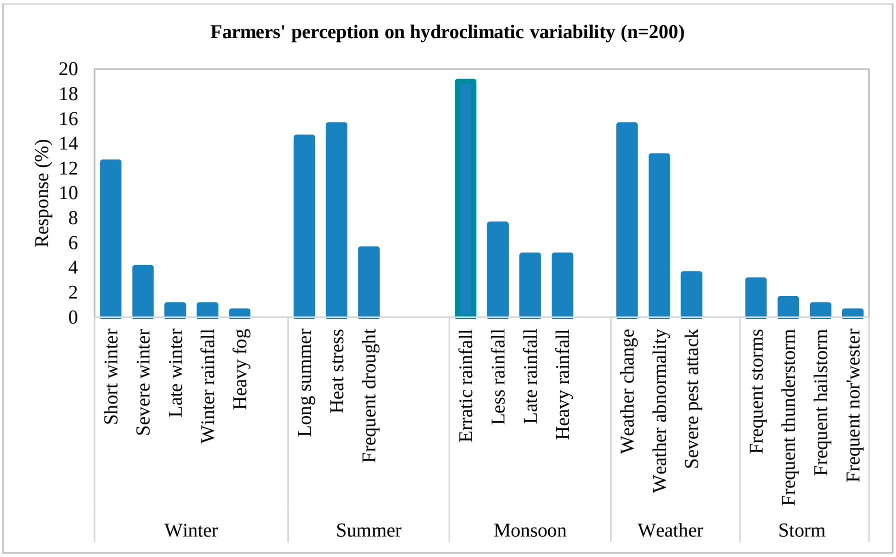

Figure 2.5. Farmers' perceptions of hydroclimatic variability in the Bengal Delta around Khulna, Bangladesh. Bar graphs show farmers' perceptions of hydroclimatic variability during three crop seasons (winter/Kharif-I, summer/Kharif-II, and monsoon/rabi) and changes in overall weather and storm characteristics in Khulna. To derive these, we asked farmers what were the major water and weather hazards for crops. Farmers revealed that a short winter, long summer, erratic rainfall, and temperature stress were the key variabilities affecting local crops and agricultural decision-making. They also reported hydroclimatic variability in terms of weather abnormality, severe pest attacks, and storm frequency.

Table 2.5. Key determinants of cropping plan decision-making, after Dury, Garcia, Reynaud, and Bergez (Dury et al., 2013).

Determinants	Sub-Groups	Description
Individual Considerations	- Personal preferences	- Personally motivated choice
	- Food security	- Food security/food stock at home
	- Tradition	- Tradition/practices from ancestors
	- Land ownership	- Land ownership status
Agronomic Considerations	-Crop characteristics	- Yield performance in the previous year(s)
		- Crop cycle and time to harvest the crop
		- Pest and disease outbreak/sensitivity
	- Soil quality	- Soil salinity and soil quality
		- Land availability for cultivation
		- Soil water content/moisture
	- Management facilities	- Field operations/activities
		- Irrigation facility
		- Fertilization
		- Weed, pest and disease control

		- Crop harvest/collection - Storage and preservation
Economic Considerations	- Profit - Cost of production - Price uncertainty -Demand uncertainty	- Profit margin high/medium/low - Input costs and availability - Labor cost and availability - Easy to sell from field to market - Crop price uncertainty/fluctuation - Crop demand uncertainty/fluctuation
Resource-Related Considerations	- Labor - Water - Technology - Finances - Scope for loan	- Labor availability - Water availability and irrigation facility - Technology support and availability - Financial situation/capacity - Loan opportunity (money/input)
Farmland-Related Considerations	- Management - Spatial - Land suitability	- Nearby or remote field distance - Transport facility to crop field - Location and accessibility of crop field - Land type (high/low/waterlogged)
Climatic Considerations	- Seasonal and short-term weather conditions - Traditional knowledge for weather predictions	- Seasonal weather conditions - Weather hazards (fog, cold spell, hail, flood, drought, hot spell, and disease outbreak) - Perception of the rainy season - Perception of the summer season - Perception of water stress and water availability
Support from Outside Actors	- National - Development agencies - NGOs	- Input support from DAE - Input support from NGOs - Education and training on new technology and cultivation practices

2.3.7 Farmers' adaptation to water stresses and the role of information

Both the farmers and the experts consulted attached a high value to the role of information in agricultural adaptation practices. All the interviewed farmers perceived hydro-climate patterns as having rapidly changed over the past 10–20 years (see Figure 2.5). One farmer interviewed in the village of Raingamari claimed that he had not gotten satisfactory production from his paddy fields the previous five years due to hydroclimatic hazards. "Now I work as a laborer instead of a sharecropper," he said. Another farmer in the same village agreed, "Rainfall does not follow the traditional rules and characteristics, and that impacts crop production and crop-related decision-making." A farmer in the village of Jharbhanga blamed human activities for the increased weather stress, "Weather is now polluted by human activities.... [N]ature is taking revenge on us through frequent weather events."

Farmers had few response options for field crops, especially during extreme events like cyclones, storm surges, heavy rains, hailstorms, droughts, and floods. Farmers and experts indicated that if these hydroclimatic events could be forecasted and communicated farther in advance with sufficient lead-time (between 1 to 2 weeks), they could at least safeguard harvested and mature crops, livestock, and farm assets. Farmers were adapting some of their management practices. Already they had increased irrigation frequency to reduce the impact of drought stress and advanced pesticide applications to limit disease outbreaks during cold spells. Farmers had also adjusted their planting times to accommodate perceived hydroclimatic changes. Hydroclimatic information services could help farmers make these decisions. Such services could also alert farmers to the need for action to limit crop damages from extreme weather. Untimely rain or irregular rain, a short winter season, an early or late start of the rainy season, a prolonged rainy season, heavy rain, floods, waterlogging, salinity intrusion, and irrigation water scarcity were the major hydroclimatic stresses reported by farmers in interviews and focus group discussions. Similarly, experts reported hydroclimatic variability in the study area, suggesting that localized and reliable information services could potentially improve local farmers' adaptation practices.

To avoid water stress in field crops, farmers in Khulna sometimes irrigated with mildly saline water. In Batiaghata, farmers reported negotiating with the local sluice operator to let in water from the river while its salinity was still relatively high, before the start of the monsoon season. Batiaghata farmers (62 of the 200 in our sample) indicated that saltwater from the river pushed through the freshwater canal, bringing the freshwater to their field more quickly. Before the saltwater reached their location, the sluice gates were closed to avoid saltwater intrusion into the boro rice fields. Farmers also applied extra chemical gypsum fertilizer to reduce the effects of salinity on field crops. Furthermore, the construction of ponds and reservoirs had become common practice around Khulna, to meet dry season irrigation demands and as an adaptation strategy to reduce water stress. Integrated farming was on the rise as well, often combining rice, fish, vegetables, and livestock. This too helped farmers adapt to increasing salinity and hydro-climate stress. Some 14–24% of the interviewed farmers had integrated farming systems (see Table 2.3).

Farmers in peri-urban Khulna had access to both formal and informal sources of information on production technologies, inputs, disease control, and ways to cope with and adapt to climate change. However, they still lacked access to hydroclimatic information services for agricultural decision-making. According to the interviewed farmers and experts, hydroclimatic information services in the study area were fragmented, top-down, and not actionable. For example, most farmers did not understand the probabilistic forecasts of BMD and BWDB, and many were unable to apply available forecasts in decision-making. Much of the forecast information was in English, and it often came too late to be of use. Farmers, extension officers, and experts alike were unaware of the existence of the BMD smartphone weather application, though the tool was available in the study area. Similarly, flood forecasts from FFWC generally did not reach farmers through extension channels. Soil and water salinity information were similarly unavailable to farmers.

SAAOs provided agricultural extension services but had limited interaction with farmers individually. Furthermore, they too had limited knowledge of hydroclimatic forecasts and thus played no role in sharing and disseminating these to farmers. One way to increase the reach of such forecasts would be to increase extension agents' affinity with them. Furthermore, extension agents could be called upon to advise on the design of forecasts and information services, to ensure their greater applicability at the local level.

2.4 Discussion

This study aimed to address three research questions regarding (1) information availability, (2) perceived quality, and (3) the role of hydroclimatic information for farmers in the Bangladesh delta. To answer these questions, we adopted an exploratory research framework combining participatory tools with analysis of climate data.

2.4.1 Information availability and farmer preferences

Our results indicate that peri-urban farmers in the Bengal Delta have access to agricultural information from five main sources: informal contacts, formal contacts, education and training programs, traditional media, and ICT/social media platforms. Farmers mainly rely on informal contacts with peers, dealers, and retailers for agriculture-related information (Miah et al., 2016, Boekel, 2016, Chaudhury et al., 2012). Interestingly, Miah et al. (2016) found a low preference for group-based sharing among fish farmers in the Muktagacha sub-district of Bangladesh, whereas we found a high preference for group-based sharing of agricultural information by farmers. Extension officers view group sharing as an effective means to disseminate information through which they can reach a large number of farmers.

Although the majority of farmers depended on informal contacts as their main source for all kinds of information, specific and effective information comes primarily through formal extension departments. Hydroclimatic information, on extremes, seasonal weather forecasts, onset, and ending of monsoon season, is hardly available to farmers via agricultural extension channels. This indicates a need to build a capacity of both farmers and extension agents to improve the communications and use of hydroclimatic information. Besides, local input dealers could be trained to provide information, as farmers attached a very high value to information coming from them. Input dealers expressed a keen interest in links with climate information services, the DAE, and the weather department (BMD). In addition, a common platform of the hydro-meteorological organizations could enhance sharing and disseminating locally specific hydroclimatic information with and for farmers. This could also enhance the quality of extension services making a direct link with local hydroclimatic information. Currently, these organizations are highly fragmented in terms of services and have no mandate to disseminate the collected information at the local level.

2.4.2 Perceived quality and role of the information available

Farmers perceived the quality of the available hydroclimatic information to be poor, insufficiently specific, and often too late to be of use in local agriculture-related decision-making (see Figure 2.4b). Many farmers in our focus groups and interview sample expressed distrust of television and radio weather forecasts, indicating they were not specific enough to meet their needs (Islam et al., 2013). Extension officers and other experts expressed similar doubts about the credibility of the available information and its relevance for the study area. As a result, farmers base most of their decisions on their own experiences and informal contacts when confronted with weather related risks and uncertainties. Currently, farmers were only partially able to respond to situations related to extreme events. They emphasized that they need more location- and lead-time-specific forecast information for tactical decision-making and to safeguard their crops, livestock, and farm assets.

Our findings show that most farmers in the study area are potentially vulnerable to increasing hydroclimatic variability (see Figure 2.5). They often depend on small fields for food and livelihood security (see Table 2.2). Previous studies have shown that vulnerability to hydroclimatic variability and reduced crop yields is affecting all three crop seasons in the study area (Talukder and Saifuzzaman, 2016). Farmers have already modified a range of cropping practices to adapt to increased hydroclimatic variability (Talukder and Saifuzzaman, 2016, Khanom, 2016, Chaudhury et al., 2012). However, the role of hydroclimatic information in agricultural decision-making is still limited, and most decisions are still driven by personal experiences and tradition (Boekel, 2016, Haigh et al., 2015, Hu et al., 2006). More educated and advanced farmers are, however, making greater use of hydroclimatic information services. This indicates that capacity building could be used to enable farmers with little or no formal education to take advantage of hydroclimatic information services in agricultural decision-making (Templeton et al., 2018, Kruk et al., 2017, Roncoli et al., 2009, Ingram et al., 2002).

2.4.3 Use of ICT in agricultural decision-making

An important question is whether and how ICT-led information services could improve extension efficiency and service coverage. Our results show that currently, only a few farmers are using ICT tools to access agricultural and hydroclimatic information. The main barriers identified were lack of ICT knowledge (81%), lack of smartphones (37%), limited understanding of the English language (50%), and poor timeliness and low perceived quality of the available information (61%). In addition, none of the interviewed farmers and only some of the extension officers were aware of existing ICT platforms as a potential source of hydroclimatic information. This is a common problem among information services designed and launched with little or no contact with end-users (Nyadzi et al., 2018, Golding et al., 2017, Lackstrom et al., 2014, Dewulf et al., 2005, Tall et al., 2014). Newly developed ICT platforms should take into account the identified barriers and ensure that platforms are known by intermediaries and the identified end-users. To achieve this there is a need for stakeholder engagement to improve information uptake and mutual learning and co-production of information services (Nyadzi et al., 2018, Kruk et al., 2017, Karpouzoglou et al., 2016). In addition, there might be potential to overcome some of the identified barriers by developing appropriately designed ICT-based services in the local language, combined with capacity building of DAE officers and farmers. Also, the increasing availability of low-cost smartphones and location-specific tailored information creates new opportunities for developing web- and app-based services.

2.4.4 Recommendations for tailoring hydroclimatic information

The results of this study point to six recommendations for tailoring hydroclimatic information for farmers. First, information platforms should use the local language and provide a local interpretation of hydroclimatic forecasts (Guido et al., 2016).

Second, the location and time specificity, and trustworthiness of forecasts should be prioritized (Lackstrom et al., 2014, Islam et al., 2013, Seo, 2010, Rengalakshmi et al., 2018).

Third, frequent interaction with farmers, via relevant training and awareness-raising programs, such as farmer field schools, should be used to develop farmers' understanding and planning culture, alongside forecast information tailored to the study area. The AIS, in cooperation with the DAE, could play a leading role in running farmer field schools and be explicitly mandated to provide hydroclimatic information along with their existing extension services to farmers.

Fourth, greater resources need to be made available for local extension services. ICT-led platforms such as smartphones are one way to effectuate an increased reach of information and extension recommendations, given a large number of farmers are still unserved for such information services. After all, 85% of the surveyed farmers already had access to mobile phones and 54% had access to a smartphone in their household.

Fifth, a detailed needs assessment is recommended to tailor hydroclimatic information services to the various groups of farmers in the study area. Information needs vary across different types of farmers, crop seasons and farming systems. Further, farmers require capacity to express their information needs, particularly where they are unfamiliar with such information services and have limited academic education background (Chavas et al., 2019, Bozzola et al., 2018, Vincent et al., 2017, Carr et al., 2016, Falco et al., 2014).

Finally, agricultural advisories should be designed using a co-production approach with and for local farmers, based on forecast information and local conditions. Co-production can lead to the creation of more usable weather advisory services and forecasts through ICT platforms, while helping to address challenges inherent in ICT-led information provision, such as equity, access, social acceptability and contextualization.

From this study, we can conclude that there is potential for hydroclimatic information services which are better tailored to the needs of the local farmers. ICT platforms such as smartphones and social media could play an increasingly vital role in tailored information exchange and communication with local farmers, to help them make climate-sensitive decisions. The current study identified 14 climate-sensitive farm decisions for which farmers and experts attributed a high value when it comes to the role that information services play, in response to a rapidly changing hydroclimatic environment, in terms of frequent variability. On a critical note, this paper also highlighted the added value that personal contact over experiences and traditional practices has for farmers. A key challenge will thus be to embed the development and introduction of any information services in a process of interaction that contextualizes the new information, thus gaining trust and facilitating the integration of scientific forecasts into daily decision-making practices.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Supplementary Material A: Farmers' Interview Form, Supplementary Material B: Focus Group

Discussion Form, Supplementary Material C: Expert Interview Form, Supplementary Material D: Climate Data Analysis.

Author Contributions: The correspondence author conducted this study supervised by Dr. Saskia Werners, Professor Fulco Ludwig, Professor Dilip Kumar Datta, and Dr. Long Hoang. The supervisors contributed substantially to the study design, editing, and commenting on article drafts for several rounds. Sharmishtha Roy and Sadia Ashraf contributed to this article through extensive fieldwork, data acquisition, and synthesis of field notes for this study.

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Conflicts of Interest: The authors declare no conflict of interest.

Note: *To include this article as thesis Chapter 2 - I made changes in reference style, the numbering of the above supplementary materials, and other minor editorial and format-related changes***.**

Chapter 3

Hydroclimatic Information Needs of Smallholder Farmers in the Lower Bengal Delta, Bangladesh

Chapter 3

Hydroclimatic Information Needs of Smallholder Farmers in the Lower Bengal Delta, Bangladesh

Abstract

Hydroclimatic information services are vital for sustainable agricultural practices in deltas. They advance adaptation practices of farmers that lead to better economic benefit through increased yields, reduced production costs, and minimized crop damage. This research explores the hydroclimatic information needs of farmers by addressing (1) what kind of information is needed by the periurban delta farmers, and (2) whether information needs have any temporal dimension that changes with time following capacity building during co-production of information services. Results reveal that the attributes of weather and water-related forecasts most affecting the farmers are rainfall, temperature, water, and soil salinity, along with extreme events such as cyclone and storm surges. The majority of the male farmers prefer one- to two-week lead-time forecasts for strategic and tactical decision-making; while female farmers prefer short-time forecasts with one-day to a week lead time that suggests the difference of purpose of the forecasts between male and female farmers. Contrarily, there is little preference for monthly, seasonal, and real-time forecasts. Information communication through a smartphone app is preferred mostly because of its easy accessibility and visualization. Farmers foresee that capacity building on acquiring hydroclimatic information is vital for agricultural decision-making. We conclude that a demand-driven coproduction of a hydroclimatic information service created through iterative interaction with and for farmers will enable the farmers to understand their information needs more explicitly.

Keywords: *Hydroclimatic information needs; farmers' decision-making; Lower Bengal Delta.*

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3.1 Introduction

Hydroclimatic information services that involve timely production, translation, and provision of water, weather, and climate-related data, information, and knowledge for climate-sensitive societal decision-making are vital for agriculture and adaptation practices in deltas (Paparrizos et al., 2020a, Nyadzi et al., 2019, Naab et al., 2019, Soares et al., 2018, Vaughan et al., 2016). It helps farmers to link their efforts to higher income, reduced input costs, and economic loss from climate risks and uncertainties (Rahaman et al., 2020, Carr et al., 2020, Nyadzi et al., 2019, Jagtap et al., 2002). The farming communities, however, in the Bengal Delta, currently stand on experience and traditional information base for agricultural practices and decision-making (Kumar et al., 2020b). They do not have access to location- and time-specific information services in a meaningful way (Kumar et al., 2020b, Rashid et al., 2014, Islam et al., 2013).

The Lower Bengal Delta—located in southwestern Bangladesh—is one of the most vulnerable deltas of the world due to climate change and sea-level rise (Ali, 1999). According to Huq et al. (2015), farming communities are highly vulnerable to different degrees of climate impacts in this delta. Smallholder farmers in the delta are highly dependent on rainfed agriculture. They face recurrent hydroclimatic disasters such as cyclones, storm surges, tidal floods, waterlogging, and saline water invasion of the crop field (Kumar et al., 2020b, Chen and Mueller, 2018). These have immense impacts on the food production system and livelihood insecurity of the smallholders (Huq et al., 2015, Lázár et al., 2015, Swapan and Gavin, 2011, Ahmed, 2008). For example, the delta farmers were the worst victims of the Super Cyclone Sidr in 2007 (Haque and Jahan, 2016, Paul et al., 2012, Paul et al., 2011), the devastating Cyclone Aila in 2009 (Kumar et al., 2010, Roy et al., 2009), the Cyclone Bulbul 2019 (Haque et al., 2019), and the recent Super Cyclone Amphan in 2020 (De and Bandyopadhyay). Besides extreme weather, the monsoon's onset is also critical for crop production in Bangladesh (Stiller-Reeve et al., 2015). It affects the country's whole crop production system with a small temporal shift and variability (Kumar et al., 2020b). Shahid (Shahid, 2010), confirms a significant increase in the annual average and premonsoon rainfall of Bangladesh. All these disaster events have had remarkable impacts on the agricultural production system. To adapt to this hydroclimatic variability in the agricultural sector, boundary organizations such as the Department of Agricultural Extension (DAE) and local stations of the Bangladesh Meteorological Department (BMD) could play a vital role to increase forecast communication and uptake. However, they need the capacity to improve their forecast understanding and confidence to provide advisory services based on hydroclimatic information (Zuma-Netshiukhwi et al., 2016).

Currently, the existing hydroclimatic information services through governmental channels are not adequate to deal with frequent hydroclimatic disturbances in the delta. The services lack information quality due to traditional communication systems, short lead-time, and lack of user engagement (Chowdhury, 2005). Indeed, the forecast information is delivered as a one-way transfer of information to farmers that limit effective usage in agricultural decision-making (Pennesi, 2011). These constraints related to credibility (i.e., perceived quality), salience (i.e., perceived relevance), and legitimacy (i.e., user interest) of the existing information services to influence farmers' decision-making (Hansen et al., 2011). Inwood and Dale (Inwood and Dale, 2019), reported that the development of a digital decision support tool requires early and ongoing engagement and interactions with the targeted end-users. Farmers cannot also understand and respond to the available information services that often come late and lack of training (Kumar et al., 2020b, Sultan et al., 2020, Hansen et al., 2011, Tall et al., 2014). A high degree of cultural belief, the experience of forecast inaccuracy, the reliance on tradition, and the local complexities in terms of weather patterns are some key factors that limit information uptake of farmers (Kumar et al., 2020b, Islam et al., 2013). A need-based service coproduction is thus essential to deal with the recurrent hydroclimatic risks and disasters in the delta. Currently, the hydroclimatic information services platforms are mostly top-down and have little or no uptake by end-users. Here, the platform means to create an improved information service in which users and producers interact to identify needs and capacities (Vaughan et al., 2016). This suggests a need-based tailored information service for delta farmers (Kumar et al., 2020b).

To achieve the goal of climate services, understanding farmers' information needs is an important aspect for tailoring hydroclimatic information services in a coproduction manner (Naab et al., 2019, Swart et al., 2017, Tall et al., 2014). To do that, forecast lead-time is one of the key attributes for tailoring information. Forecast lead-time is classified as historical or past climate records, real-time or near real-time information, short-range weather forecasts of about one week, medium-range weather forecasts of about two weeks, and long-range weather forecasts and climate predictions such as monthly, seasonal and interannual time scales (Ogallo et al., 2000). Forecasts less than a month, such as real-time information or near real-time, daily, weekly, and ten-day, are vital for agricultural decision-making. To date, many forecasting models struggle with predictivity below 10 days (Kim et al., 2019). Gensini et al. (2020), found that forecast skills are higher between two- versus three-week lead-time. Robertson et al. (2019), developed calibrated probabilistic forecasts for northern India for up to two weeks. They found appreciable skills for about one-week lead-time (days 3–9) with some skill at two weeks (days 10–16). In a seminal case study Gbangou et al. (2019), notices that the

European Centre for Medium-Range Weather Forecasts (ECMWF) System 4 seasonal climate forecast has a significant skill to predict seasonal onset variability at the local scale in Ghana, West Africa.

In the existing services, misalignment exists between information needs and information that is being provided to the intended end-users (Vaughan and Dessai, 2014). Literature suggests that a typical user survey is not enough to understand climate impacts and sensitivities in a region and to resolve mismatches between climate science products and user needs (Clifford et al., 2020). Here, user needs are defined as the hydrological and meteorological parameters that are important to farmers for agricultural decision-making. This does not take place automatically without careful consideration, and it often requires iterative interaction and capacity building of the intermediaries and end-user farmers (Kumar et al., 2020b, Carr et al., 2020). Available literature reveals that due to the disregarding of users' needs, information uptake is poor and less useable, and useful to the targeted end-users (Soares et al., 2018, Tall et al., 2018, Rasmussen et al., 2014). However, assessing the information needs of farmers is not a simple task. The literature indicates that this is particularly difficult and time- and budget-demanding, and it includes relevant tasks for which people are either unfamiliar and/or have limited academic education and lack of capacity towards understanding and use such services for agricultural decision-making (Vincent et al., 2017, Carr et al., 2016, Daly and Dessai, 2018).

This research provides insight into the issue of 'understanding farmers' information needs' which is vital for better design information services for smallholders in agricultural decision-making (Vaughan et al., 2016). Following the existing literature, we hypothesized that understanding information needs is not just a single-step process. Information needs may change with time, such as the capacity building of the smallholder farmers. To test the hypothesis, iterative interaction and capacity building is an obligatory task to address information needs and better design information services for farmers. In this study, two research questions were addressed: (1) What kind of information is needed by the periurban delta farmers? (2) Do information needs have any temporal dimension that changes with time following capacity building during coproduction of information services with and for farmers in the delta? This research would help, besides farmers, researchers, and policymakers to understand hydroclimatic information needs in a developing context where farmers and extension services have limited training and capacity on hydroclimatic information services for agricultural decision-making. This research would also help scientists, service providers, and developers for tailoring information for farmers in a coproduction manner.

3.2 Materials and Methods

3.2.1 Study area

The study was conducted in three villages: *Jharbhanga, Sanchibunia,* and *Raingemari*, which are located in the Batiaghta Upazila (subdistrict) in periurban Khulna (Figure 3.1). The Khulna region represents the core of the Lower Bengal Delta. There were about 250 households in these three villages where 61% of the population are engaged in agriculture, 28% in service, and 9% in the industry sector. The region represents a low-lying coastal morphology that experiences frequent hydroclimatic hazards such as cyclones and storm surges, salinity invasions, and waterlogging [10]. The Rupsa-Bhairab-Pasur in the east and the Mayur river in the western boundary of the city play a key role in the agriculture-aquaculture farming systems of the area under investigation (Roy et al., 2018).

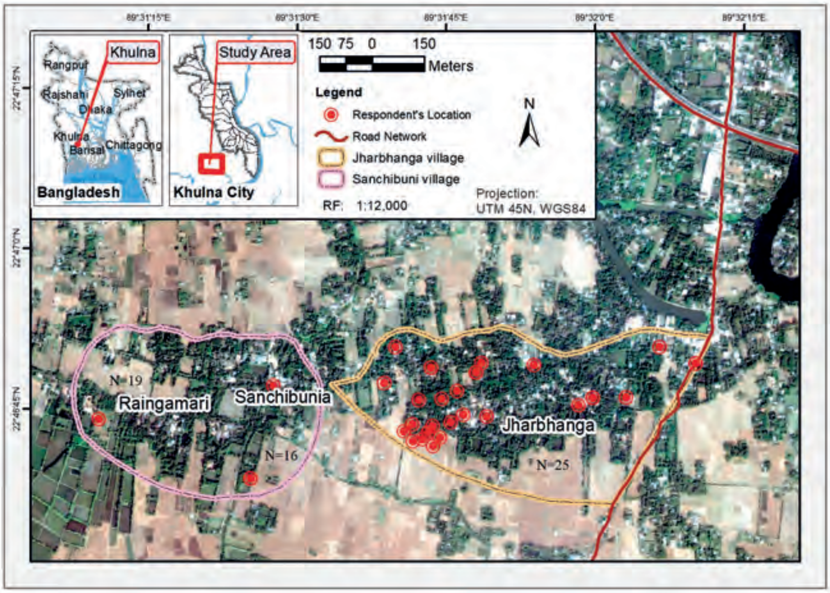

Figure 3.1. General location of the study area with point location of the sampled households or surveyed village locations in Batiaghta Upazila in periurban Khulna Bangladesh. At Jharbhanga village interviews (N = 25) were conducted at individual farmers' households. At Sanchibunia and Raingamari villages, interviews (N = 16 + 19 = 35) were conducted at three village points of the farmers' households.

Farming around periurban Khulna comprises three distinct crop seasons, the Rabi (November–March), Kharif-I (March–June), and Kharif-II (June–November). The region enjoys a subtropical warm and humid climate with four distinct seasons (Shahid, 2010). The average annual rainfall is 1752.3 mm and the mean annual temperature is 26.7 °C. The average monthly minimum and maximum temperatures are 21.9 to 31.3 °C, respectively. January is the coldest month with a mean minimum temperature of 12.9 °C and April is the warmest month of the year with a mean maximum temperature of 34.9 °C. About 80–90% of the rainfall takes place during the monsoon months of May to October (Mondol et al., 2018b, Shahid, 2010). The highest rainfall occurs in July and the lowest in December with monthly averages of 327.6 mm and 4.5 mm, respectively. High annual rainfall provides an excellent opportunity for agricultural practices in rain-fed conditions in the study area (MoA and FAO, 2013).

3.2.2 Site selection

A total of nine periurban villages was visited during reconnaissance visits. Five villages, *Badamtala*, *Mailmara*, *Jharbhanga*, *Sanchibunia*, and *Raingamari*, were visited in the Batiaghata subdistrict and four villages, *Mohishagunni*, *Sreefaltala*, Domra, and Payara were visited in the Rupsa subdistricts. Farmers were interviewed randomly during reconnaissance visits to explore local cultivation practices and to gain prior knowledge of the prevailing hydroclimatic vulnerability. We observed a similar cultivation pattern at all periurban villages surveyed that involves two major rice crops (T-aman and Boro) with varieties of vegetable cultivation practices round the year at homesteads and agriculture-aquaculture farming systems. Subsequently, three periurban sites *Jharbhanga*, *Sanchibunia*, and *Raingamari* were selected at the Batiaghata subdistrict for further interactions and capacity building of farmers and data collection for this study, which are depicted in Figure 3.1. The selected villages are easily accessible from the city of Khulna due to proximity and they additionally present typical periurban physiognomies for the general area, having both rural and urban landscapes, socioeconomic linkages, and livelihood interdependency.

3.2.3 Data collection

The primary data were collected through baseline and endline assessments conducted from February 2018 to April 2019. The schematic representation of the data framework is depicted in Figure 3.2; Figure 3.3. The baseline assessment includes reconnaissance field visits and meetings with farmers and semi-structured personal interviews with 60 periurban farmers selected for this study (Supplementary Materials 3A). These activities help us to understand the information needs of selected farmers' groups at baseline conditions. The endline assessment includes a second round of personal interviews with the same questionnaire and farmers' groups, followed by farmers' engagement, training, and weekly interaction meetings. Results from the baseline and endline assessment were compared to discourse farmers' needs and to assess how that information needs change with interactions and capacity building of farmers. The farmers that were selected for this study had experience in hydroclimatic information services using a smartphone and their application in agricultural decision-making. Thus, the farmers' capacity building training was conducted at the study villages through farmer field schools (FFS) with the help of the local extension office (DAE). FFS is a group-based agricultural extension approach of DAE.

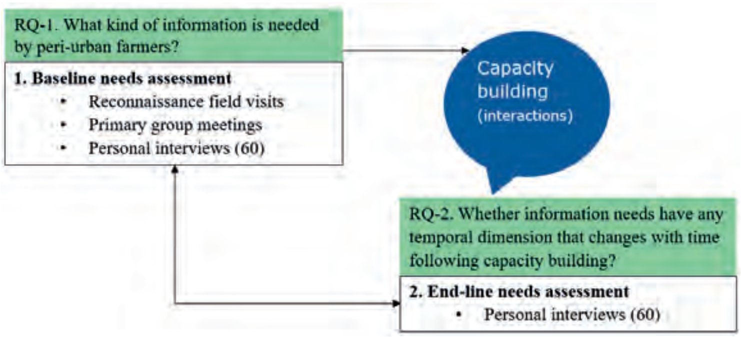

Figure 3.2. Primary data collection framework including the steps and participatory tools that were employed in the current study.

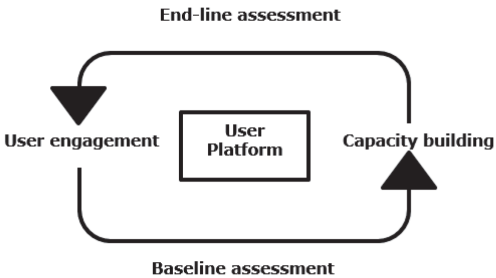

Figure 3.3. A five-step farmer engagement process for understanding the information needs of smallholder farmers in the Lower Bengal Delta.

We engaged two farmers' groups through FFS during three crop seasons (Kharif-I: March to July; Kharif-II: July to November; Rabi/Boro: November to March) and provided Meteoblue (Meteoblue, 2019) forecasts for seven and 14 days, and seasonal (three-month) weather forecasts as well as training on their interpretation and advisory services with the help of the local agricultural extension office. An example of the provided Meteoblue forecast is given in (Supplementary Materials 3B). Three kinds of face-to-face interaction were provided through the FFS: (1) general discussion and comments on the weekly provided forecast information (seven-day, 14-day and three-month forecasts); (2) group learning through elaboration and discussion on the forecasts and their interpretation; and (3) agricultural advisory and decision-making based on the forecasts in a participatory way together with the experts from local agricultural extension department (Supplementary Materials 3C). Relevant secondary data were retrieved through desk research from relevant research articles, databases of the Bangladesh Bureau of Statistics (BBS), and unpublished database and reports of the local extension office.

A five-step user engagement process helped us to understand the information needs of smallholder farmers and to collect primary data through an interactive process for this research (Figure 3.3). User engagement and capacity building are two main iterative components that are activated under users' platforms such as FFS [6,9]. Finally, a baseline and an endline assessment were conducted to compare information needs for better design information services with and for the farmers.

3.2.4 Baseline needs assessment

Three primary meetings were conducted at *Jharbhanga*, *Sanchibunia*, and *Raingamari* villages. The meetings were conducted with the listed farmers' groups of the local extension office. There were 25–30 households in each farmers' group, which represented 50–60 farmers, considering husbands and wives as group members. For the primary meetings, we invited a single participant (either male (husband) or female (wife)) from the farmers' households. We engaged participants for about 2 h for mapping: (i) major crops, (ii) key decision points, and (iii) agricultural information sources in a flipchart paper. We discussed what they do to confront hydroclimatic hazards and how they currently access hydroclimatic information services for agricultural decision-making. The major hydroclimatic hazards indicated by farmers were untimely heavy rainfall, waterlogging, cyclones, thunderstorms, hailstorms, temperature stresses (drought and cold stress), heavy fog, salinity invasion, etc. Finally, we discussed information needs, forecasts availability, lead-time, and their future interest in information services for agricultural practices and decision-making. At this instant, the lead-time denotes forecast information in sufficient advance time scales so that farmers can take action for saving crops and other livelihood assets from hydroclimatic risks and variability. In these meetings, we got an idea about hydroclimatic risks and climate-sensitive key decisions of farmers. We also conducted a primary meeting with the district and subdistrict extension officers of the DAE to discuss and triangulate the hydroclimatic information needs by farmers. The extension officers (N = 6) commented on information needs for farmers, current availability, and required lead-time. After the primary meetings, a total of 60 farmers were interviewed using a semistructured questionnaire for a detailed understanding of their needs for managing hydroclimatic risks and uncertainties. Among them, N = 25 of farmers were from *Jharbhanga* village, N = 16 farmers were from *Sanchibunia* village and N = 19 farmers were from *Raingamari* village. Figure 3.1 shows farmers' locations in the study villages. The questionnaire focused on the weather- and water-related information needs, forecasts' lead-time, the preferred method of communication, and the format of the needed information (Supplementary Materials 3A). The respondents were selected randomly from the listed farmers' groups of DAE in the selected villages. At least 30% of participants we considered were female.

3.2.5 Endline needs assessment

After capacity building, training, and frequent interaction with farmers, we noticed changes in hydroclimatic information needs, lead-time, and parameters of interest such as a thunderstorm, hailstorm, water and soil salinity, cold stress, fog, etc. Lead-time implies advance forecast information in sufficient advance time scales such as (sub-) daily, weekly, monthly, seasonal, etc. for taking climate-sensitive decision-making. Following changes in farmers' information needs, we interviewed the same experimental farmers' groups for the second round for their endline needs assessment. All these farmers also participated in the weekly interaction and training we had initiated through FFS for the coproduction of hydroclimatic information services with and for periurban delta farmers.

3.2.6 Data analysis

The collected qualitative data such as field observation notes, group meetings notes, and farmers' comments were organized, coded, summarized in Word files, and Excel datasheets for further analysis and interpretation. The primary quantitative data that were collected through interviews were then coded and analyzed using the SPSS software (Version 23) for the preparation of a results summary in tabular format. The graphs were generated from the quantitative results using python 2.7 software. The study area point data were collected using Google Earth and finally, the map was prepared using ArcGIS software.

3.3 Results

3.3.1 Demographic profile of farmers

The demographic details of the farmers are presented in Table 3.1. Female farmers were mainly involved in homestead agricultural activities that include cultivation of vegetables, livestock rearing, compost preparation, crop processing, storage, and other supportive activities for field crops. In contrast, the male farmers were involved in field crop production, day-to-day farm management, and tactical decision-making. The majority of the farmers were between 26–40 (37%) and 41–60 (35%) years old. A total of 22% of farmers were above 60 years old and a few (7%) were young farmers between

18–25 years old. Education status shows that a total of 35% of farmers were educated at the primary level, 27% were educated at the secondary level and 20% were educated at the higher secondary level. A total of 18% of farmers had no formal academic education. The average household size of the farmers was five persons. In detail, 63% of farmers had a family size of three to six people, 17% had a family size of one to two people and 20% had a household size above six people. In the study sites, most farmers had more than 10 years of experience in farming activities. A total of 33% of farmers had farming experience between one and 10 years. Among interviewed farmers, 65% of farmers have leased lands for agricultural practices. However, 77% of the total farmers had personal land ownership and 33% of farmers had no land ownership for agricultural activities. The monthly income range indicated that about half of the farmers could earn five thousand Bangladesh Taka (BDT) or less which is less than two US dollars per day. A total of 23% of farmers were fully dependent on agricultural incomes and the majority of them (77%) were involved in off-farm incomes in the cities and peripheral areas. The average farm size of smallholder farmers was 182 decimals with a minimum and maximum farm size of 6 and 675 decimals, which includes personal and lease lands.

Table 3.1. Descriptive statistics of the respondents (Source: Baseline survey).

Variable	N = 60	%	Variable (N = 60)	N = 60	%
Gender			Farm Experience		
Male	38	63	1–10 years	20	33
Female	22	37	11–20 years	18	30
Age			21–30 years	7	12
18–25	4	7	Above 30 years	15	25
26–40	22	37	Land ownership		
41–60	21	35	Yes	40	67
Above 60	13	22	No	20	33
Education			Monthly income (BDT)		
Primary	21	35	1–5000	31	52
Secondary	16	27	5001–10,000	15	25
HSC	12	20	10,001–20,000	14	23
Illiterate	11	18	Off-farm income		
Family size			Yes	46	77
1–2	10	17	No	14	23

3–6	38	63	Farm size (decimal)	
Above 6	12	20	Average	182
			Minimum	6
			Maximum	675

3.3.2 Hydroclimatic challenges and information needs of farmers

Information gathered from primary meetings is summarized in Table 3.2. The major products during Kharif-I are short-duration vegetables and oilseeds, while rice is the main product for the Kharif-II (T-aman rice) and Rabi (Boro rice) seasons. Farmers face different hydroclimatic challenges during the three crop seasons. The Nor'wester (thunderstorms)—locally named *Kalboishakhi*—during Kharif-I is characterized by sudden thunderstorms, hailstorms, and cyclones with heavy rainfall. Additionally, drought and scarcity of irrigation water is also a common characteristic of Kharif-I crop season in the entire delta. Water in the rivers and canals is highly saline during the Kharif-I as reported by the local farmers. On the other hand, the Kharif-II season is characterized by heavy rainfall, waterlogging, storm surges, and cyclones. The majority of the farmers reported that they cannot go to the crop fields regularly during the Kharif-II season due to heavy rain and storms. The Rabi crop season remains cold and dry with frequent cold spells, drought, and intense fog. Farmers indicated that winter rainfall and cyclone events during the Rabi season often damage mature rice fields and that have been more frequent in the study area in the last few years.

Table 3.2. Summary of the season-specific hydroclimatic information needs of smallholder farmers in the Lower Bengal Delta.

Crop Seasons	Major Crops	Hydroclimatic Challenges	Information Needs	Forecast Lead-Time
Kharif-I (Summer) (Mid-March to Mid-June)	Vegetables and oil seeds	Nor'wester or Kalboishakhi, hailstorm, drought, water scarcity, etc.	Rainfall, thunderstorm, and cyclone	Seasonal; monthly; 1–2 weeks; 1–3 days
Kharif-II (Monsoon) (Mid-June to Mid-November)	Taman paddy and summer vegetables	Heavy rain or less rain, drought, waterlogging, storm surge, and cyclones	Rainfall, dry days, temperature, thunderstorm, and cyclone	
Rabi (Winter) (Mid-November to Mid-March)	Boro paddy and winter vegetables	Cold spells, storm surge, and cyclones, winter rain, fog, drought, etc.	Rainfall, cold spells, sunshine duration, thunderstorm, and cyclone	

Local farmers reported that an indication of weather information, such as rainfall intensity and precise timing and cyclone and thunderstorm signals, one to two weeks in advance would reduce their unexpected crop damages through taking climate-sensitive decisions. In addition, an indication of monthly to seasonal weather forecasts would help farmers to make strategic and more sophisticated decisions such as crop selection, cultivation decision, land allocation, and choice of crop variety. For example, sesame is commonly cultivated during Kharif-I in the study area. Sesame is a highly profitable and short duration crop to farmers. However, if farmers have indications about heavy rainfall occurrences in Kharif-I, they would not go for large-scale sesame production particularly in low lands. Sesame fields are sensitive to waterlogging conditions. On the other hand, if farmers perceived a very heavy rainfall during Kharif-II in advance they would prefer to grow local varies of T-aman rice instead of hybrid rice in the low lands. The stem height of hybrid rice is low, thus expected production might be affected due to the waterlogging problem. Overall, in the primary meetings, farmers reported lead-time hydroclimatic forecast information on rainfall, temperature, thunderstorms, cyclones, cold spells, and sunny or dry weather days. About 90% of the farmers revealed that one to two weeks of advanced forecast would reduce their crop damages by 60–80% in the harvest period. However, about 60% of farmers also indicated that thunderstorm and rainfall forecast one to three days in advance would also reduce major hydroclimatic risks and damages through taking tactical decisions such as hazard preparedness, collection of harvested crops, repair of farmers' households, repair of farmhouses, and keeping farm assets and livestock at a safe place. Farmers said that they do not allow livestock in the field during a thunderstorm and rainy weather conditions. They could also manage fodder for livestock if they perceived thunderstorms, cyclones, and rainy weather conditions for consecutive days.

3.3.3 How did information needs change between baseline and endline interviews?

3.3.3.1 Weather-related information needs

The weather information needs of farmers shifted from the baseline assessment (Figure 3.4) except for that of information on rainfall (such as monsoon onset, amount, duration, etc.). During the endline assessment, about half of the farmers indicated that forecasts on high-temperature and intense rainfall are two important parameters of interest to predict drought and waterlogging situations in advance. This would help farmers to save crops from drought and waterlogging conditions by taking advanced measures such as subsistence irrigation and excavation of drainage systems in crop fields. Paddy farmers said that sometimes irrigation by brackish water is inevitable during a prolonged drought period. In contrast, they use a pump to get rid of waterlogging, especially during the ripening stage. The majority of the farmers during endline assessment indicated that forecasts of hailstorms, cyclones, and storm surges, and fog are vital for agricultural decision-making. This means that information needs may change over time due to the capacity building of farmers. Thus, to tailor information services for farmers, capacity building is required to understand the detailed information needs of the smallholder farmers.

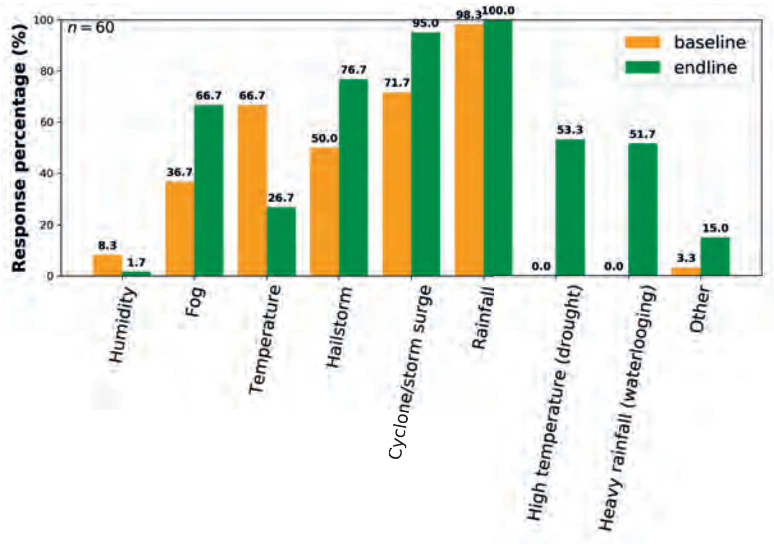

Figure 3.4. Baseline versus endline weather information needs of smallholder farmers in the Lower Bengal Delta around Khulna, Bangladesh.

3.3.3.2 Water-related information needs

The majority of the farmers during the baseline needs assessment indicated that they require forecasts on the flood, water and soil salinity, and river discharge (Figure 3.5). This information could assist them in selecting crops based on land conditions. Such forecasts help them in selecting local varieties that are more resilient to flooding conditions, while, during endline interviews, only 2% of the farmers reported flood forecasts as an information need and none of the farmers reported river discharge as an information need. The farmers realized that, since their paddy fields are located in a poldered (embanked) entity, they are not susceptible to recurrent and severe floods and are well protected from high river discharge during the monsoon. Indeed, farmers in these villages face short-term waterlogging and drainage congestion during intense rainfall. They added that the waterlogging is mainly due to encroachment of the natural drains and canals by local elites, who often acquire these natural drains and canals for aquaculture through the governmental leasing process. Frequent interaction and training may improve farmers' capacity to address these aforementioned local issues and information needs. This concludes that limited interaction with farmers is not sufficient to identify the appropriate information needs for tailoring hydroclimatic information services. Endline assessment also confirms that water and soil salinity is the most important parameter of interest to farmers for agricultural decision-making in the local context to deal with increased hydroclimatic vulnerability.

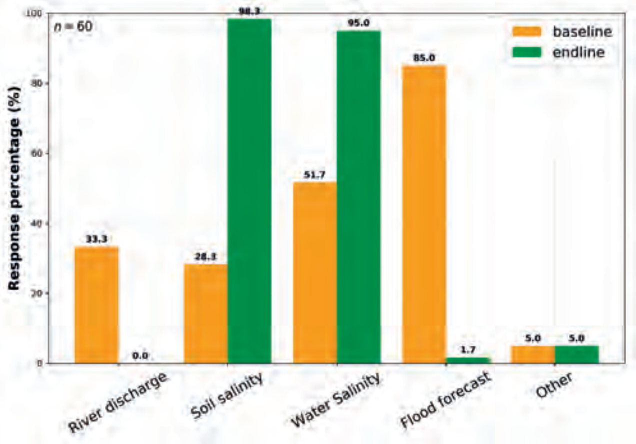

Figure 3.5. Baseline versus endline water information needs of periurban farmers in the Lower Bengal Delta.

3.3.4 Lead-time information needs

About half (48%) of the farmers were interested in receiving two-week to one-month forecasts in advance for agricultural decision-making during the baseline needs assessment (Figure 3.6). However, a total of 38% of farmers were interested in receiving weekly forecasts and 42% were interested in real-time forecasts. A few of them (18%) opted for seasonal (three-month) and two to three-day advanced forecasts (15%). However, during the endline assessment, farmers indicated that they mainly take agricultural decisions for one to two weeks at current practices. Thus, they were less intended for a monthly to seasonal scale planning culture for agricultural decision-making. Besides, the traditional rice farmers said that they do not take decisions for more than one to two weeks in advance. They reported monthly and seasonal scale forecast accuracy was not useful in their current agricultural decision-making practices. We also observed that forecast accuracy significantly differs between the one-week and two-week timescale. Very few farmers (3.3%) reported that the monthly to seasonal forecasts were useful for agricultural decision-making. Figure 3.5 shows that needs for one to two weeks forecast were expressed by the majority of the farmers in the study area. This concludes that farmers require less but more specific information than what they have expressed during the baseline assessment. They also reveal that monthly to seasonal scale information quality is not good enough for precise decision-making. A short lead-time forecast (one week or less) is more appropriate and applied for precise agricultural decision-making.

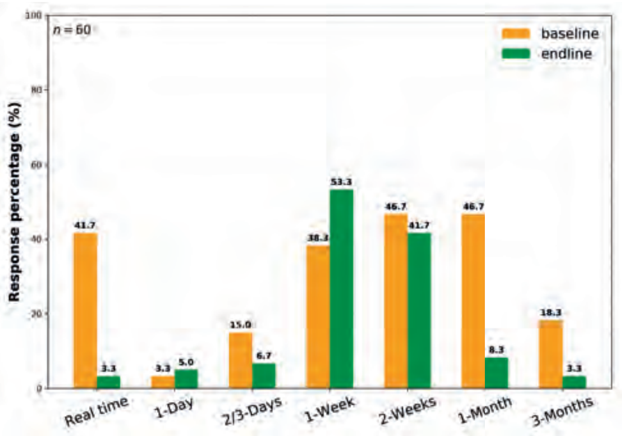

Figure 3.6. Baseline versus endline lead-time of hydroclimatic information needs of smallholder farmers in periurban areas of the Lower Bengal Delta.

3.3.5 Choice of the communication platform

Farmers do not prefer traditional information platforms such as radio and television for agricultural decision-making (Figure 3.7). Currently, ICT-led platforms such as smartphones and social media are more preferable and accessible for weather and climate-related information services. In the face-to-face meetings during the FFS, farmers reported that forecasts (i.e., Meteoblue; see Supplementary Materials 3B) through a smartphone do not require extra time to access information. In the baseline and endline comparison, results revealed that after capacity training and interactions, 81% of farmers were interested to receive weather information services through a smartphone. However, before training, the majority of the farmers (85%) stated that they lack ICT skills to receive information through a smartphone. Hence, farmers' interaction and training could overcome the existing usage barriers concerning access to ICT tools such as smartphones and help farmers to efficiently uptake hydroclimatic information for agricultural decision-making.

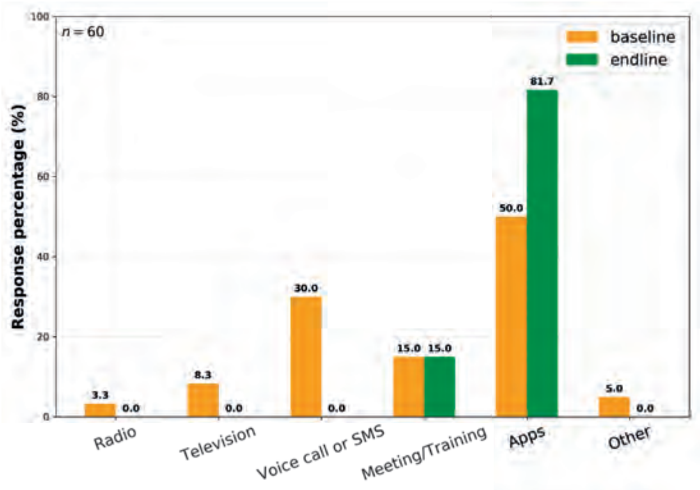

Figure 3.7. Farmers preferred communication platforms for receiving hydroclimatic information service in periurban areas of the Lower Bengal Delta. Here 'other' includes in-person communication with individual farmers or lead-farmers in a village for delivering hydroclimatic information services by the field extension officers.

3.3.6 Format of the information

The results indicate that farmers prefer more visualization for receiving forecasts such as photographs or diagram based rather than a written text format (Figure 3.8). They opined that the visual format is easy to understand by looking at the symbols for different weather phenomena such as rain, thunderstorm, sunshine, etc. Initially, the farmers raised some concerns about the use of visual images to gain a clear understanding of activities during the succeeding weeks. However, through iterative interaction, farmers showed a clear interest in a diagrams based forecast than in the text-based written information (See Supplementary Materials 3B). This was also more useful for people with little or no literacy, as reported by the farmers during FFS and endline interviews. The bar-plots that depicted probability percentages (%) in the visual diagrams were more acceptable than the line plots, to make them understand the severity and accuracy of the forecasts and the predicted events.

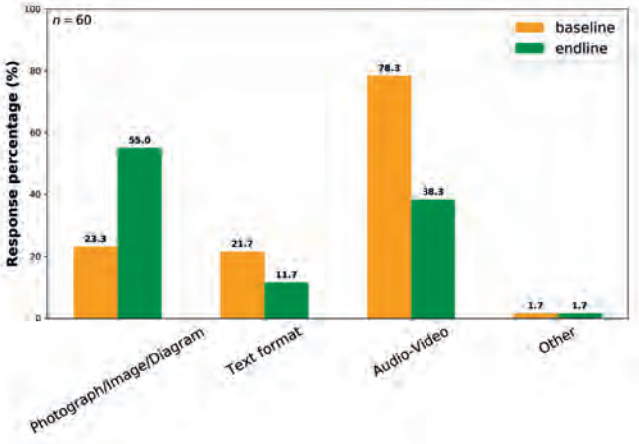

Figure 3.8. Farmers' preferred formats for receiving hydroclimatic information service in the Lower Bengal Delta.

3.4. Discussion

3.4.1 What kind of information is needed by farmers?

Farmers face different kinds of hydroclimatic challenges in the Lower Bengal Delta (Table 1). The results show that information needs have four key dimensions: (1) water or hydrological information, (2) meteorological information, (3) soil quality information, and (4) emergency weather forecast. During interviews and focus group meetings, farmers reported that information forecasts on these four key dimensions would help them in strategic and tactical decision-making. The local extension officers, however, indicated that together with the weather- and climate-related information, farmers also need advisory services on technology and agronomic variables such as modern cultivation methods and diversified crop varieties for precise agricultural decision-making based on local hydroclimatic conditions (Ingram et al., 2002). All this information is vital and interconnected for agricultural decision-making. Stone and Meinke (2006) also observed that farmers need advisory services on seasonal variability to adjust farming practices that best suit the upcoming season and take advantage of weather forecast information (Ingram et al., 2002). The majority of farmers are currently facing challenges while taking agricultural decisions due to increased hydroclimatic variability (Islam et al., 2013). For example, some farmers at *Jharbhanga*, *Sanchibunia*, and *Raingamari* villages stated that "the current weather does not follow any traditional rules, and we often made wrong decisions based on our traditional understanding".

In the current study, the hydroclimatic information needs of farmers were compared between baseline and endline assessment. The results indicate that farmers expressed a more general outlook during the baseline information needs assessment. The key information needs were rainfall, cyclones and storm surges, hailstorms, fog, temperature, and humidity. However, during the endline needs assessment, farmers were more specific to express their information needs, required timescales, and preferred platforms. This might impact capacity building through training as well as farmers' engagement and frequent interactions with forecast services. For example, during the endline assessment, farmers reported that forecasts on extreme temperature and heavy rainfall were more important for managing drought and waterlogging risks. The majority of farmers indicated that emergency forecasts such as cyclone formation and storm surges are vital for their tactical decision-making.

Boekel (2016), found out that there is a huge gap between information needs and available information for sesame farmers in the study area. (Bernardi, 2011) reported similar results with farmers of eastern Australia where the available forecast does not meet the farmers' needs. Interestingly, Boekel (2016), did not address any hydroclimatic information needs of the sesame farmers in the Lower Bengal Delta. However, during the current study, all farmers and extension officers reported that sesame is the most affected crop in this delta area due to weather variability such as a sudden heavy rainfall during the Kharif-I (pre-monsoon). Farmers and extension officers reported that sesame is one of the most popular crops in the entire delta due to high price and short crop cycle. However, currently, sesame cultivation has been reduced due to an increased trend of heavy rainfall in the delta during the Kharif-I season (Jodder et al., 2016, Rashid et al., 2014).

Information lead-time may vary among users such as farmers, agency owners, and policymakers. For strategic and policy-oriented decision-making, the forecast lead-time may include a short-time-scale forecast (weekly to bi-weekly), the climate prediction in a medium-time scale (monthly to seasonal, and decadal-scale), and the climate projection in a long time-scale (10–30–50 years) (Boekel, 2016, Finucane et al., 2013). In this research, forecast lead-time includes weekly, bi-weekly, and seasonal lead-time for farm scales decision-making. To assess that we used an open-ended response for providing more freedom to the interviewee farmers regarding their needed time-scale for hydroclimatic information services. However, we found a shift of forecast lead-time between baseline and endline assessment. The forecast lead-time was more inclined towards weekly and bi-weekly scales during the endline needs assessment. Smallholder farmers reported that they were well experienced in traditional cultivation seasons and cropping practices. Thus, they mostly need a short timescale information service to help them in tactical and operational farm management decisions based on local hydroclimatic variability. Only the farmers with academic education and a good farming knowledge (~12%) reported that monthly or seasonal scale information would help them for taking more strategic decisions such as crop selection, land allocation (high and low land and amount to be cultivated), seasonal water availability (quality, quantity, and timing) and input collection in advance for the upcoming season. The female farmers, however, requested one to three days' forecast information for household and farming activities such as vegetable production, processing crops, and firewood, dung-stick preparation (for fuel), fodder collection, and management of livestock and farm assets.

Similar studies, such as Nyadzi et al. (2019), found that farmers in northern Ghana preferred information on a monthly scale before the season for strategic decision-making. However, in the Lower Bengal Delta, most farmers prefer one to two weeks of lead-time for strategic as well as tactical decision-making. A few farmers with academic education and knowledge on cultivation requested monthly to seasonal forecasts for strategic decision-making. Farmers mentioned that cyclone and storm surge forecasts are crucial, especially during the paddy harvesting period. They reported that a good forecast during the paddy harvesting period could reduce crop damages up to 60–80% that also fundamentally liked the food security issue of the smallholder farmers of the delta. The forecast lead-time needs may also be different based on field location, farm size, ease of transportation, and expected crop yields added by the respondent farmers during interviews. For example, if a farmer's field is located at a remote distance and the farm size is large enough, then more advanced information is needed compared to a small paddy farm located close to the farmers' households. On the other hand, if farmers do not expect satisfactory production then they are less interested to invest in labor and transportation costs for crop harvest and collection, and they require more advanced forecasts for harvest by themselves. The female farmers, in contrast, reported that a weekly lead-time forecast is enough for their households' level of farming and livestock management activities. Carr, Fleming, and Kalala (Carr et al., 2016) also reveal that even at the village level, the women have different information needs and forecast lead-time. The gender-sensitive information needs thus should be considered to improve uptake (access and use) of information services for agricultural decision-making [30,42]. Besides gender, Carr et al. (2020), and Roncoli et al. (2011), revealed that the sociocultural factors also influence farmers' engagement process and uptake of hydroclimatic information and they should be carefully addressed during information provision and service coproduction.

In the primary meetings, farmers did not discourse about the choice of communication platform and format for the forecast information. However, during baseline and endline assessment, we addressed these two important design principles with the local farmers that indicated a significant change between baseline and endline assessment. After capacity building, mobile-app (82%) and diagram-based (55%) forecasts were mostly preferred by the majority of farmers (see Figure 3.7; Figure 3.8). Kumar et al. (2020b) found that about 54% of farm households already have access to smartphones in the study area, and the majority of them were connected to a social media app such as Facebook. Thus, a smartphone app such as social media could play a vital role in providing forecasts and advisory services to farmers translating information into the local language. After capacity building, experimental farmers also requested to continue sharing the Meteoblue forecast diagrams (seven days, 14 days, and three months) through creating a messenger group. In addition, farmers said that they would share these forecasts with their family, peers, and relatives involved in agricultural activities. In this direction, Inwood and Dale (2019), also found a need for mobile applications as a digital decision support tool for emphasizing knowledge exchange rather than just some information delivery. However, in sub-Saharan Africa, Feleke (2015), found that more than half of the farmers still depend on the radio as the preferred communication platform. A few model farmers knew about the technology and its uses in sub-Saharan Africa. Farmers in Zambia also requested weekly to seasonal forecasts through community radio (Stigter et al., 2014). This indicates that the choice of platform and information lead-time may vary from place to place during the coproduction of location-specific hydroclimatic information services (Ingram et al., 2002). In the study area, ICT-led platform such as mobile app is most preferred but traditional platforms such as FFS, radio, and television may also have a wider application based on community preferences, availability of technology, socioeconomics, and cultural perspectives.

3.4.2 Do information needs change over time and capacity building?

3.4.2.1 Knowledge improvement of farmers

The results revealed that capacity building has increased the knowledge of farmers about hydroclimatic information (Figure 3.9). During the baseline needs assessment, the majority of farmers' knowledge of hydroclimatic information was poor (n = 45%) to moderate (~48%). However, during the endline assessment, farmers (~80%) reported an increased knowledge level due to interactions and capacity building. Among them, about 68% of farmers claim that they currently have good knowledge and 10% of farmers claim an excellent knowledge of hydroclimatic information. Moreover, farmers also reported a wide range of limitations towards the uptake of the available hydroclimatic information during the baseline assessment (Figure 3.10). However, following interaction and capacity building, farmers only reported the lack of smartphones and the lack of ICT knowledge as their key limitations to uptake information. Other limitations such as economic reasons, incompatible design, internet unavailability, etc. weren't reported by farmers during the endline needs assessment. Interactions and capacity building of farmers improved their knowledge base as well as their understanding, which helped them to express needs more precisely based on local hydroclimatic vulnerabilities. Sultan et al. (2020), found out that lack of training and capacity building is an important barrier apart from the stakeholder engagement for better uptake information services by the end-users.

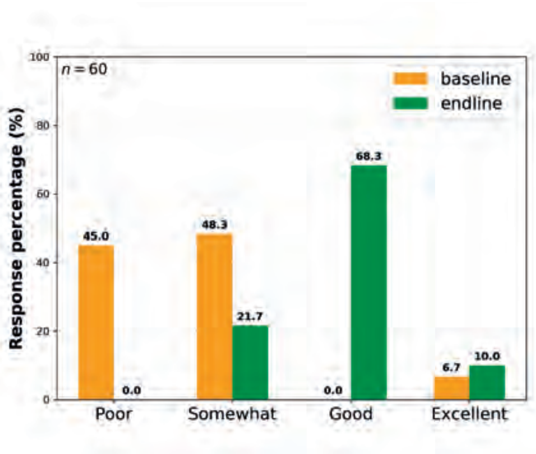

Figure 3.9. The baseline and endline comparison of farmers' knowledge of hydroclimatic information in the study area.

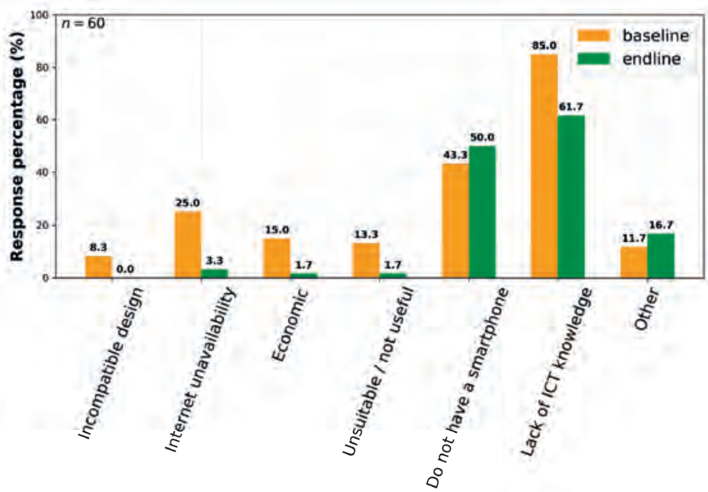

Figure 3.10. Limitations of uptake available hydroclimatic information by periurban farmers in the Lower Bengal Delta, Khulna, Bangladesh.

3.4.2.2 Farmers' engagement process

There is no ideal approach for user engagement (Daly and Dessai, 2018). This study engaged farmers and agricultural extension services. Lack of engagement with relevant end-users limits the effective uptake of information services (Soares et al., 2018, Bernardi, 2011). Similar studies found a critical role of iterative interaction between end-users and service producers for understanding information needs (Vincent et al., 2017, Kruk et al., 2017, Daly and Dessai, 2018). They also revealed that the lack of user understanding and capacity limits the uptake of forecast information in decision-making. In the current study, a participatory engagement process was followed where farmers and local extension officers were actively involved in knowledge coproduction (Kruk et al., 2017). The results showed that user engagement not only builds trust and a positive relationship between the information provider and users but also improves community confidence to deal with the frequent hydroclimatic hazards and to better respond to the provisioned forecasts and provide feedback on the overall quality of the information services. Initial engagement of farmers through the farmers' field school (FFS) provided an excellent opportunity for service coproduction in a participatory way where users discussed their specific needs, accessibility, relevance, and particular usage (Jagtap et al., 2002). Results revealed that farmers often had difficulty expressing their needs, particularly as they were not familiar with hydroclimatic information services and have limited or no academic literacy (Vincent et al., 2017, Feleke, 2015). However, the FFS platform helped towards addressing this issue through weekly interaction and participatory training with the help of the local extension office.

3.5 Conclusions

This study confirmed that information needs shifted over time as farmers gained better understanding and experience on the use of location-specific hydroclimatic information services. A better understanding of information needs is thus vital, requiring participatory interaction and capacity building. It also helps smallholder farmers to better understand forecast information for climate-sensitive decisions following capacity building and frequent interaction during the coproduction of information services. A series of participatory interactions enabled farmers adequately to express their specific information needs. We thus conclude that understanding needs is not a single-step process. It should consider a baseline and endline assessment with capacity building training, considering all crop seasons, local agricultural practices, socioeconomics, culture, and technological perspectives of the users. Tools such as Participatory Integrated Climate Service for Agriculture (PICSA) can be useful for step-by-step interaction and capacity building training for farmers (Dorward et al., 2015).

Secondly, why and how did the needs change, and by what processes? This study concludes that change in needs resulted when farmers had a better understanding through a series of participatory interactions and the provision of information services help through a learning process over time. We followed a coproduction approach that followed stepwise farmer engagement processes (see Figure 3.3). The engagement process and steps may vary, based on the capacity and local contexts of the target audience. For example, financial organizations and policymakers require information on a regional and long-term perspective such as climate predictions (monthly to seasonal) and projections on a (multi-) decadal scale. They may not need participatory interactions with baseline and endline assessment. This study was performed with a limited number of farmers in a coastal periurban context in the lower Bengal Delta. Thus, the hydroclimatic challenges and information needs might be different in other regions and or even in the same region as the users can access and uptake weather and climate information services more frequently and with higher local precision. Cultivation practices, seasonal variability, technology, and other socioeconomic dimensions also need special attention to understand the needs and to better design information services to influence farmers' decision-making. Finally, we conclude that a primary need assessment is not adequate for developing hydroclimatic information services when farmers do not have a proper understanding of what is delivered at the community level, and what they need. An iterative approach thus can provide the best outcome for understanding farmers' needs with capacity building and coproduction information services with and for farmers.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Supplementary Material A: Farmers' baseline/endline needs assessment questionnaire, Supplementary Material B: Waterapps Climate School Khulna, Bangladesh—Meteoblue ensemble forecasts, Supplementary Material C: Waterapps Climate School—Farmers Field School (FFS) Protocol Expert Interview Form.

Author Contributions: The correspondence author conducted this study supervised by S.W., F.L., D.K.D., and S.P. The supervisors contributed substantially in the study design, editing and commenting on the draft article for several rounds, and visited field sites during data acquisition of this study.

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Conflicts of Interest: The authors declare no conflict of interest.

Note: *To include this article as thesis Chapter 3 - I made changes in reference style, the numbering of the above supplementary materials, and other minor editorial and format-related changes***.**

Chapter 4

Co-producing Climate Information Services with Smallholder Farmers in the Lower Bengal Delta: How Forecast Visualization and Communication Support Farmers' Decision-making

Chapter 4

Co-producing Climate Information Services with Smallholder Farmers in the Lower Bengal Delta: how forecast visualization and communication support farmers' decision-making

Abstract

Farmers in the Bengal Delta are confronted with increasing hydroclimatic risks due to climate variability and change. Co-produced climate information services that address the farmers' needs could potentially assist farmers with climate-sensitive decision-making and managing their risks. This study aims to investigate how the co-production of climate information services through forecast visualization and communication has improved forecast uptake for climate-sensitive decision-making of smallholder farmers. We applied a farmer field school approach to communicating visual diagrams for 7-day, 14-day, and seasonal forecasts during face-to-face meetings using printed paper, and smartphone applications. Results show that diagram-based forecast visualization and a combined communication approach integrating face-to-face interaction using printer paper and a smartphone app have improved uptake of information services by farmers. Capacity building and frequent interactions at farmer field schools contribute to a better understanding and trust of visual forecasts, interpretation skills, and decision-making capacity of smallholder farmers. We conclude that the co-production effort with farmers combined with the capacity building has resulted in wider sharing, dissemination, and uptake of scientific forecasts for climate-sensitive decision-making by smallholders in the Lower Bengal Delta.

Keywords: *Climate information services, co-production, forecast visualization and communication, agricultural decision-making, Bangladesh*

This Chapter is submitted as:

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4.1. Introduction

The agriculture sector is pivotal in the national food and livelihood security of Bangladesh. The sector employs about 85% of people in rural areas by direct and indirect means (Sikder and Xiaoying, 2014) – thus assists in sustaining the rural economy, and contributes to about 15-20% of national GDP (Clarke et al., 2015, Kashem et al., 2010, BBS, 2018). The agricultural production of southwest Bangladesh is affected by hydroclimatic variability and extreme events such as floods, droughts, cyclones, and storm surges (Kundu et al., 2020, Dasgupta et al., 2015a, Mallick et al., 2017). Smallholders are mostly affected by these recurrent hydroclimatic variabilities (Huq et al., 2015). Climate studies (Dasgupta et al., 2015b, Masood et al., 2015, Mirza, 2002, Faisal and Parveen, 2004) indicate that hydroclimatic variability and associated risks will have an enormous impact on agricultural practices of smallholders, and insecurity of food and livelihood will prevail particularly in the Lower Bengal Delta (Ortiz, 1994, Huq et al., 2015). Adaptation to increased hydroclimatic variability is thus essential for the food and livelihood security of smallholders. Location-specific climatic information services are needed to assist farmers in the Bengal Delta (Kundu et al., 2020). Here climate information service is defined as the production, translation, distribution, and uses of weather and climate information for (agricultural) decision-making (Vaughan and Dessai, 2014, FAO, 2019).

The current climate information services in the Bengal Delta have several limitations such as awareness, understanding, time- and location-specificity, particularly at the farmers' level (Islam et al., 2013, Schulenburg et al., 2017, DAE, 2018b, Ahmed et al., 2019). The national hydro-meteorological organizations follow a mostly top-down approach that hampers smallholders to express their specific information needs in the production, translation, and distribution process. The current agrometeorological forecast information has a short-time scale (~7-day) with numeric data and information that smallholder farmers hardly understand. Lack of understanding limits the uptake of such top-down climate services, and these are often very late for a specific action (Ahmed et al., 2019). Information uptake is defined as access to and use of climate information services in agricultural decision-making. The Bangladesh Meteorological Department (BMD) has made significant progress in climatic information services in cooperation with national and international agencies. BMD forecast has a positive role in managing extreme hydroclimatic events such as cyclones and storm surges by disseminating early warnings (Habib et al., 2012). However, day-to-day location-specific climatic services are still scarce among farming communities vital for sustainable food production in the Bengal Delta. So there is an urgent need for climatic information services to support smallholders' decision-making (Ahmed et al., 2019, DAE, 2018b).

The smallholders in the Bengal Delta suffer from (mis)understanding, (in)accuracy, and irrelevance of the current climatic services provided by the national hydro-meteorological services (DAE, 2018b, Islam et al., 2013). Beyond technical issues, socio-cultural attributes such as age, gender, literacy, farm-size, traditional belief, and personal risk behaviour also contribute to the uptake of currently available climate information services. Therefore, farmers base most of their decisions on tradition and experience pertaining to agricultural decision-making (Kumar et al., 2020b, Ahmed et al., 2019). The co-production of climate information services can improve farmers' information uptake and decision-making (Gbangou et al., 2020a, Kumar et al., 2021, Nyadzi et al., 2019). Co-production refers to iterative science and a mutual learning process with users to develop and communicate weather and climatic information services for societal decision-making (Vedeld et al., 2019, Lemos and Morehouse, 2005, Bremer et al., 2019, Gbangou et al., 2020a). A bottom-up co-production effort is often observed as the best approach for developing climate information services with farmers (Nyadzi et al., 2019, Gbangou et al., 2020a, Wall et al., 2017, Bremer and Meisch, 2017, Vincent et al., 2018). However, the co-production of climate information services should take into account farmers' engagement, trust, and capacity building, and cost-effective technology to overcome communication challenges (Bacci et al., 2020, Kumar et al., 2020a, Nyadzi et al., 2019).

Forecast visualization is an essential attribute for improving the usefulness and usability of climate information by decision-makers (Lorenz et al., 2015). Forecast visualization refers to processing numeric climate data and information into visual means such as animation, pictures, graphs, and charts that enable decision-makers to conceptualise better and understand the climate information (McCaslin et al., 2000). While social and communication science has shown that visual communication techniques significantly impact the decision-making process (Lorenz et al., 2015), it is less addressed in climate service studies (Drake et al., 2016). However, with visualization technique, complex data and information can be represented in a simple manner that can influence users' engagement, interpretation, and uptake including individual interest and local relevance of climate information (Nicholson-Cole, 2005, Lorenz et al., 2015). Previous studies showed that better visualization results in a better understanding and communication of the inherent uncertainty of model-based forecasts (Ruginski et al., 2016, Nadav-Greenberg et al., 2008). A co-production process, including a focus on improved forecast visualization, improves the chance that climate service is understood, trusted, and used by the farmers to make decisions. A better visualization may also evoke the smallholders' emotional attachment towards forecasts (Keeling, 2010) and its uses for important decision-making. The rapid expansion of smartphone technology could play a vital role for improved forecast visualization and communication with smallholders. Therefore, visual forecasts with a smartphone platform can be effectively used to support smallholder producers for managing climate risk and informed agricultural decision-making.

The existing constraints can be addressed through a need-based co-production process with frequent interactions with farmers and digital tools (Owusu et al., 2020, Gbangou et al., 2020a, Ofoegbu and New, 2021). However, the current climate services are still mostly supply-driven with limited co-production efforts (Carr and Onzere, 2018, Vedeld et al., 2019, Ofoegbu and New, 2020). Therefore, there is limited empirical evidence that climate services can be as effective as claimed (Vincent et al., 2018, Bremer et al., 2019). This study aims to investigate how the co-production of climate information services through forecasts visualization and communication has improved information uptake for climate-sensitive decision-making of smallholders. In this study, we applied a farmer field school approach to deliver 7-day, 14-day, and seasonal forecasts information during the face-to-face meeting using printed paper, and smartphone applications during the Kharif-II (T-aman) crop season from mid-June to mid-November in 2019.

4.2 Materials and Methods

4.2.1 Study area

The study area Khulna is one of the most vulnerable regions in Bangladesh due to climate change impacts and hydroclimatic variability (Chen and Mueller, 2018, Dasgupta et al., 2015a, Minar et al., 2013, Karim and Mimura, 2008, Karim et al., 2013, Clarke et al., 2015). Farmers around Khulna practice diverse cropping activities during three crop seasons: *Kharif-I* (Mid-March to Mid-July), *Kharif-II* (Mid-July to Mid-November), and *Rabi* (Mid-November to Mid-March). The major agricultural activities are dominated by rice-fish and year-round vegetable production in the study area (Rashid et al., 2017, Rashid et al., 2014).

The study area is located in a hot and humid subtropical climate zone having four distinct hydroclimatic seasons, pre-monsoon (March-June), monsoon (July-August), post-monsoon (September-October), and winter (November-February) (Shahid, 2010). The annual average rainfall over the period 1948-2018 was 1752 mm and the mean temperature was 26.7^0 C (Kumar et al., 2020b). The annual maximum and minimum temperatures are 35.5^0 C and 12.5^0 C (Rashid et al., 2019). An increasing trend of rainfall in post-monsoon and winter periods significantly impacts crop production (Hossain et al., 2014). About 70-90% of the annual rainfall occurs during monsoon months from May to October (Shahid, 2010). A high rainfall status provides an excellent opportunity for agriculture-aquaculture farming practices in the delta. Studies show that inter-annual rainfall variability has been changed. The trend indicates that monsoon onset dates have shifted to later in the year with a potentially reduced monsoon season length (Hossain et al., 2014, Paparrizos et al., 2020b). This increases the pressure on smallholder farmers using rainfed farming practices.

This study is conducted at *Sanchibunia* and *Basurabad* (*Madia Asannagar*) villages in the Batiagahata subdistrict (Figure 4.1). The Batiaghata is an agriculturally dominated and moderately salt-affected subdistrict of Khulna. There are about 767 households in two study villages with a total population of about 3265 (BBS, 2012). The Batiaghata is located in the core of the lower Bengal Delta in Khulna, Bangladesh. Farmers in the peri-urban area are highly dependent on nature-based livelihoods such as agriculture and fisheries. About 63% of farmers are solely engaged in crop agriculture in the area (Haider et al., 2011). The Batiaghata holds an area of 248.31 sq. km sited between 22°34' and 22°46' north latitudes and between 89°24' and 89°37' east longitudes, and belongs to the Agro-Ecological Zone 13: Ganges Tidal Floodplain (Rashid et al., 2019, BBS, 2012). It is surrounded by the city Khulna and Rupsa *Upazilas* in the north, Dacope and Paikgachha *Upazilas* in the south, Fakirhat, and Rampal *Upazilas* of Bagerhat district in the east, and Dumuria *Upazila* in the west.

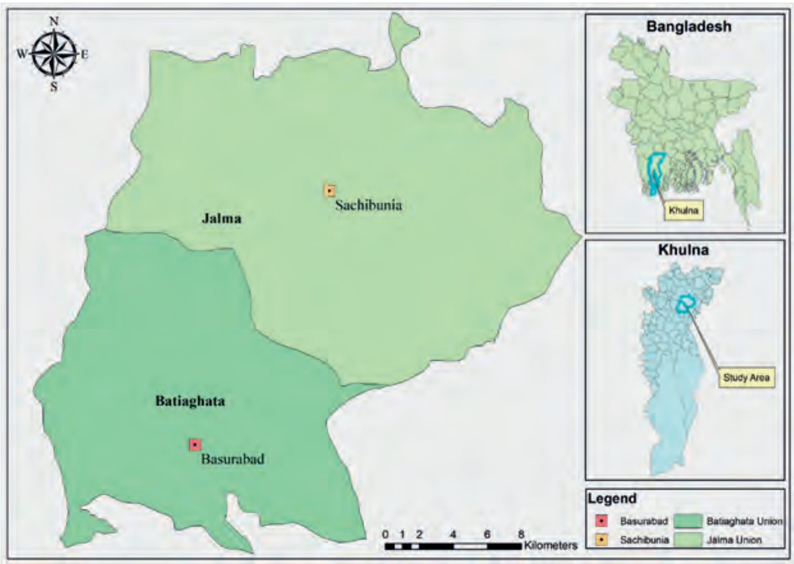
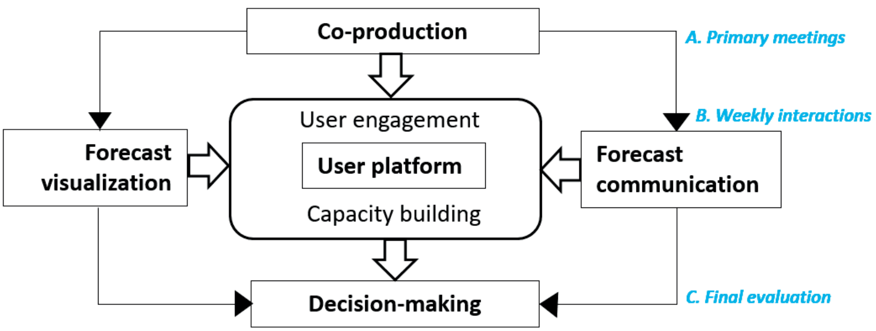


Figure 4.1. General location maps of study sites in Batiaghata *Upazila* of Khulna, Bangladesh (right maps). A total of n=58 smallholder farmers were engaged at *Sanchibunia* and *Basurabad* villages (left map) during Kharif-II (*T-aman*) crop season for the co-production of climatic information services with farmers followed by participatory training and weekly interactions.

4.2.2 The co-production process

Figure 4.2 shows the co-production process and data collection framework. Following a baseline and needs assessment study (Kumar et al 2020[a,b]), two Farmer Field Schools (hereafter FFS) were designed at *Sanchibunia* and *Basurabad* villages for the co-production of climate information services with smallholders. The villages and farmers were selected from the local extension office's listed farmers' groups, followed by field visits and interviews with farmers (n=50). It took about a month to design and set up the experimental FFS through primary meetings with local extension officers and selected farmers. 58 smallholders were involved in the experimental field schools, including both male (n=35) and female (n=23) farmers. The FFS was conducted during the *T-aman* (*Kharif-II*: mid-June to mid-November) rice season in 2019. *T-aman* is the most important crop season for farmers in the Lower Bengal Delta for rainfed agricultural practices.

Farmers' opinions about lead-time information needs were assessed by baseline (Kumar et al., 2020b) and information needs assessment (Kumar et al., 2020a). We shared 7-day, 14-day, and seasonal (3-month) visualized forecasts with farmers during face-to-face meetings using printed paper and smartphone applications. The forecast diagrams were retrieved weekly using the meteoblue[1] image API-URL and were disseminated to farmers accordingly (Supplementary Materials 3B). A written protocol was followed for conducting weekly meetings at FFS (Supplementary Materials 3C). The duration of the FFS session was about one and half hour divided into three sub-sessions: (1) general feedback session concerning information quality of the shared forecast diagrams and agricultural decisions made by farmers; (2) group learning session for discussion and interpretation of forecast diagrams for next weeks and season; and (3) participatory advisory session for developing weekly and next season advisory services with the help of a local extension officer.



[1] https://www.meteoblue.com

Figure 4.2. Schematic representation of the conceptual framework followed in the current study for the co-production of climate information services to assist smallholder farmers' decision-making. The data collection framework included A. primary meetings, B. weekly interactions, and C. the final evaluation phase. Forecast visualization and communication are used as the key attributes during weekly interaction to co-produce climate information services with and for smallholder farmers in the Lower Bengal Delta.

During the weekly FFS sessions, we shared forecast diagrams in three different modes of communication: (1) oral sharing of forecast diagrams during face-to-face meetings, (2) supply of the forecast diagrams with printed paper, and (3) sharing forecast diagrams in the messenger app. These three communication modes are identified by the farmers and local extension officers in the meetings. The majority of farmers have access to a smartphone (71%) in the study area, and the majority of them are also using Facebook for personal and social communication. They desire frequent sharing, update, and communication of the forecast information creating a messenger app group. We repeated the same for the first four weeks as an inspiration and selecting the preferred way of forecast communication with experimental farmers. Finally, the majority of the farmers at *Sanchibunia* and *Basurabad* villages give an opinion to continue the three communication modes during the ongoing T-aman crop season.

Based on the farmers' opinion, we continue sharing the forecast diagrams retrieved from the meteoblue image API-URL. We conducted weekly meetings using a semi-structured checklist for feedback collection and participatory discussion with farmers (Supplementary Materials 4A). Finally, the experiment was completed, followed by the final evaluation interviews and group meetings conducted during January and February 2020. About one-third of experimental farmers lack smartphone and internet facilities to access forecast information during co-production. Increased access to smartphones and ICT facilities can improve forecasts communication and uptake by farmers. Thus, we provided two tablets (Model- Huawei MediaPad T3 10) to two experimental farmers' groups with a full-time internet facility to have shared access to the ICT facility of the experimental farmers. We engaged two Master's students of Khulna University, Bangladesh, during capacity building and participatory interactions with farmers. They assisted farmers during the discussion and interpretation of forecast information to better understand and act on the forecast information. They also supported farmers with downloading and installing mobile applications and added them to the app group.

4.2.3 Data collection

We collected qualitative and quantitative data through field observation, meetings with farmers and local extension officers, weekly monitoring and participatory interactions, and final evaluation through interviews. Secondary data about study sites were collected from the local agriculture offices, national statistical databases, and published literature. Three primary meetings were conducted with DAE extension officers and two farmers' groups to assist on-site selection, setup of the experimental field schools, understanding of local agricultural practices, and hydroclimatic challenges for crop production and livelihood activities. An FFS protocol and semi-structured questionnaire were applied for data collecting during weekly FFS sessions (Supplementary Materials 3C & 4A). Typical metrics-based evaluation processes are difficult to apply for the co-production approach (Vincent et al., 2018, Wall et al., 2017). In this study, we conducted a total of n=55 individual farmer interviews out of 58 experimental farmers (male 31, female 24) with semi-structured quantitative and qualitative questionnaires for the final evaluation of climate services (see Vedeld et al., 2019).

The quantitative interviews were conducted using www.kobotoolbox.org, an online survey tool (Supplementary Materials 4B), and the qualitative interviews (Supplementary Materials 4C) were conducted using a printed version of the questionnaire. The final evaluation questionnaires focused on six sub-sections: Part A: General questions on, demographic, socio-economic, and farming practices; Part B: Forecast sources and uses during the experimental period; Part C: Modes of forecast communication; Part D: Aspects of forecasts visualization; Part E: Forecast quality, (in)accuracy and uptake in decision-making; and Part F: Use of forecasts for emergency response and disaster management. Together the quantitative and qualitative interviews took about 90 minutes. As the interview time was relatively long, we advance appointments with farmers over the telephone and/or personal contact. For the interviews, the majority of male farmers preferred the evening, while the majority of female farmers preferred the afternoon.

We carefully discussed research tools and data collection processes with farmers, including the notion of the co-production of climate services during primary meetings, participatory interactions, and final interviews. We explained to farmers why authentic and responsible responses were critical during monitoring and evaluation. We also explained about overestimation and underestimation of information services and their drawbacks. Two group meetings were conducted at the end of the crop season for final feedback collection regarding forecast visualization and communication modes. The co-production of climate services helps farmers improve their farming practices and decision-making during numerous extreme hydroclimatic events. In the final meetings, we also discussed the possible future continuation of climate information services using the ICT platform such as app with the extension officers' help and leading farmers actively involved in the study.

4.2.4 Data analysis

The collected data, such as field observation and meeting notes, were organized and coded in Microsoft word and excel for further analysis and interpretation. The weekly monitoring and evaluation, qualitative feedback, and qualitative interview data were organized, coded, and analysed through content analysis in excel. The quantitative data collected through online interviews were organized and coded in excel and analysed using SPSS software (version 23). The summary statistics generated from the SPSS and transferred in excel for tables and graphical presentation of the results. The study villages' GPS locations were collected using a smartphone to show in location map of the study villages. Finally, the study area map was prepared using ArcGIS software.

4.3 Results

4.3.1 Profile of experimental farmers

The farmers' profiles are presented in Table 4.1. The average household size of the farmers is four persons. The majority acquired education above the primary level. About half of them (45%) have farming experience of more than ten years. A good number (53%) of farmers are sharecroppers practicing agriculture in cultivable land between 1-5 acres. Only 2% of farmers have cultivable lands of more than 10 acres. Agriculture is the primary source of the income of households. However, currently, only agricultural income is often not sufficient for their livelihood. Thus many of them (58%) are engaged in alternative income sources such as small trade in cities and retail labour at the peripheral villages. The female farmers in Khulna play a vital role in agricultural activities and decision-making. They are engaged in both the homestead and farm-scale agricultural activities and perform a dynamic role in agricultural systems such as crop production, livestock rearing, crop processing, and storage. Besides, female farmers also process dung-based organic fertilizer at the homestead level for use in crop fields and generate supplemental household income. About 71% of farmers have access to smartphones. About one-third (29%) of farmers confront financial limitations in purchasing a personal smartphone and internet package. They also confess their lack of ICT knowledge and personal awareness and network instability that limit access and usage of smartphones in utilizing climate information services for agricultural decision-making.

Table 4.1: Profile of the experimental farmers.

Variables	n=55	Percentage (%)	Variables	n=55	Percentage (%)
Respondent			Land ownership		
Basurabad FFS	25	45	Personal	26	47
Sanchibunia FFS	30	55	Leased	6	11
			Persona and leased	23	42
Gender			Cultivable land		
Male	31	56	(acres)	45	82
Female	24	44	1-5	9	16
			6-10	1	2
			10-above		
Education			Agri. income (%)		
Primary	2	4	0-40	7	13
Secondary	18	33	41-60	19	35
Higher Secondary	13	24	61-80	15	27
Graduate	22	40	80-above	14	25
Family size			Alternative income		
1-3	24	44	Yes	32	58
4-6	27	49	No	23	41
Above 6	4	7			
Age group (year)			Smartphone access		
20-29	24	44	Yes	39	71
30-39	18	33	No	16	29
40-49	7	13			
50-above	6	10			
Agri. experience (year)			Smartphone access		
0-10	30	55	Male	25	64
11-20	16	29	Female	14	36
21-30	5	9			
31-above	4	7			

4.3.2 How forecasts visualization has shaped understanding and forecast uptake

4. 3.2.1 Understanding forecast through visualization

Following the evaluation phase, the majority of the farmers indicated that they had acquired an excellent understanding of forecast information through visual diagrams (Figure 4.3). A few farmers (4-13%) lack personal capacity in understanding the forecast visually. They prefer weekly interaction by taking notes of 7-day, 14-day, and seasonal slots of forecasts for agricultural practices and decision-making. The weekly interactions enhance farmers' capacity in grasping climate information from the visual forecast diagrams. The weekly interactions also built trust in forecasts and that their confidence in applying forecasts for agricultural decision-making. Farmers suggest the 14-day forecast diagram is handy at the beginning of the cropping season and during the harvest period. However, about 90% of smallholder farmers prefer a short-time forecast (7-day diagram) for agricultural decision-making. The seasonal (3-month) forecast is followed by a few farmers (6%) in agricultural decision-making. Also, farmers opined that a forecast of 1-3-day in advance is very useful for daily engagements at the homestead and farm scales such as crop processing, livestock management, fertilizer and pesticide application, and labour hiring.

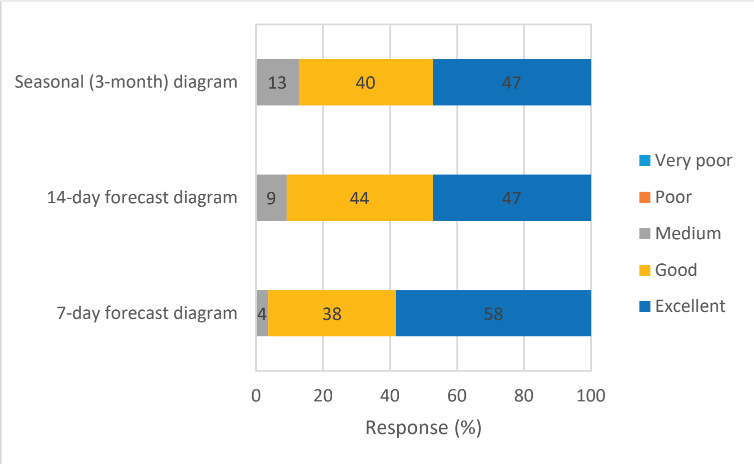


Figure 4.3. Farmers' opinion about the understanding of the weather information that was visualized through the 7-day, 14-day, and seasonal (3-months) forecast diagrams in the Lower Bengal Delta. Five points (excellent, good, medium, poor, and very poor) Likert scale were applied to evaluate farmers' understanding of forecasts.

Figure 4.4 shows farmers' understanding of specific parameters from visual forecast diagrams. The majority of the farmers (44-58%) are confident of acquiring an excellent knowledge of assimilating forecasts (such as rainfall (or shower), maximum and min temperature, cloud coverage, etc. during the Kharif-II (T-aman) cropping season. A good number (18-47%) of farmers opined that they assimilated a good interpretation skill of forecasts through repeated weekly interactions. The major parameters included in the shared forecast diagrams are temperature (maximum and minimum), rainfall, wind speed, cloud coverage, relative humidity, etc., and their associated predictability and probability (Supplementary Material 3B). Grasping weather forecasts and understanding the parameters is low among a few farmers (2-9%). Involvement with FFS has enhanced appreciation of forecast information to about 16-33% of the farmers. Farmers often discuss their peers for intelligible understandings of the forecast, suggesting that peer farmers play a role in forecast interpretation in an interactive co-production process.

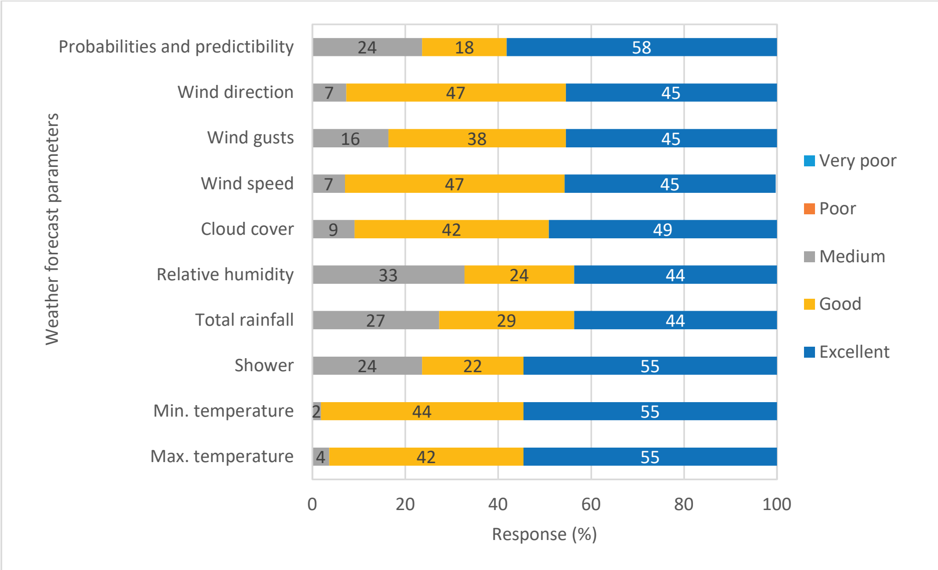


Figure 4.4. Farmers' opinions about understanding the specific weather parameters that were visualized through the 7-day, 14-day, and seasonal (3-month) forecast diagrams in the lower Bengal Delta. Five points (excellent, good, medium, poor, and very poor) Likert scale were applied to evaluate farmers' understanding of specific forecast parameters.

4.3.2.2 Uptake forecasts through visualization

The results show that forecast uptake was easy to about 93% of farmers through visualization. With a better understanding and interpretation skills through forecast visualization, 91% of farmers uptake the 7-day forecast diagram for agricultural decision-making because they perceive it has superior accuracy. Also, they can memorize the 7-day information with ease and advisory services can be co-produced in weekly interactions in presence of the local extension officers. Farmers reported that the 7-day forecast is convenient to uptake even without having a smartphone at home.

One-third of farmers reported that they also frequently uptake the 14-day forecasts because the 14-day forecast diagram is more useful for planning and performing agricultural activities following 2-week weather conditions. Rainfall forecast has a better visualization bar-chart in the 14-day diagram. Farmers know that the forecast accuracy is related to lead-time. However, the majority (>80%) of farmers said that the quality of the 14-day forecast was good enough for strategic decision-making such as crop harvest. All farmers perceive the usefulness of seasonal forecasts for strategic decisions such as crop choice, variety selection, land preparation, and advance collection of input from reliable sources. However, only three farmers used the seasonal forecast (3-month) for planning the next crop season. Currently, farmers involved in traditional rice-based farming practices do not use and access the seasonal forecast. Indeed, all farmers prefer seasonal forecasts in advance (~1-month) of the crop seasons.

Regarding key benefits of the specific forecast diagrams, results show that the uptake of visual forecast diagrams spreads over both for day-to-day agricultural and non-agricultural decision-making. Such a visual forecast offers the optimum application of fertilizer and pesticides in the rice fields and vegetable gardens. During qualitative interviews, farmers' opinions regarding 7-day forecast characteristics are useful in decision-making (58%), excellent forecast quality (49%), and easy to understand (47%). While, the major features of the 14-day forecast diagram are forecast lead-time (84%), forecast quality (15%), and visible rain-bars (7%) with probability percentages. The perceived characteristics of the seasonal forecast are in crop planning (42%), strategic decision-making (33%), and crop variety selection (25%). The farmers have a soft attitude towards less accurate forecasts and even favours such forecast in(accuracy) as they perceive that alertness is good to avoid frequent economic loss and crop damages from extreme hydroclimatic events.

4.3.3 How communication has shaped forecast understanding and uptake

4.3.3.1 Modes of forecast communication

We have communicated 7-day, 14-day, and seasonal forecasts for farmers weekly in three different modes (Figure 4.5). About 84% of the farmers opined that face-to-face communication is an excellent approach at initiation and this has enhanced forecast uptake significantly among the farmers in agricultural decision-making. Face-to-face interaction and communication provide step-by-step training and skills for assimilating forecast interpretation and improve understanding of forecast probability and (in)accuracy. Farmers added that before joining FFS, they had no understanding of forecast probability and forecast (in)accuracy (uncertainty) in the weather forecast information.

Many farmers (29-55%) also favoured app-based forecast communication and uptake weekly, followed by capacity building training and weekly interaction meetings. These farmers have access to smartphones and the internet for receiving forecasts either on their own or from peers. However, around 16% of farmers have difficulties in accessing internet facilities. They are more interested in receiving the visual forecast diagrams over the printed paper during face-to-face meetings. However, it is observed that generally, paper-based communication is also appreciated by a large number of farmers.

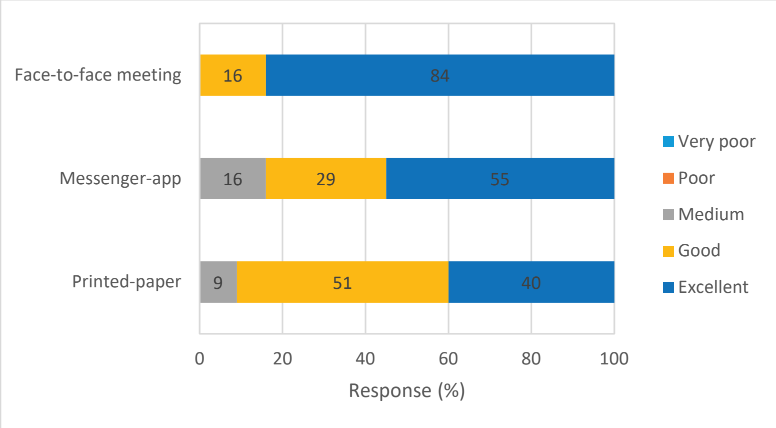


Figure 4.5. Three main communication modes were employed in the current study (F2F meeting, Messenger-app, and Printed-paper), and farmers' perceptions on quality of communication modes. Five points (excellent, good, medium, poor, and very poor) Likert scale were applied to evaluate various forecast communication modes.

4.3.3.2 Lead-time forecast communication, forecast quality, and uptake

The qualitative interviews reveal that a significant number of farmers (>90%) are sceptic about the performance of weather forecasts having 1-2 week time-scale in the beginning. The 1-2 week time-scale is not familiar to them. However, forecasts regarding extreme events such as cyclone and storm surge by radio and television media are quite familiar and have a lead time of a few days. However, following weekly FFS interactions, the experimental farmers were convinced that 7-day and 14-day forecasts are compatible with the study area's prevailing weather conditions. They are now progressively motivated toward the uptake of the lead-time forecasts in decision-making.

Farmers highly value the 7-day forecast. It is perceived as 60-80% precise by study farmers. The 14-day forecast is perceived as 50-70% precise by the farmers. About 33% of farmers certify the 14-day forecast as excellent, considering its time-scale for tactical and strategic decision-making. About 38% of farmers also consider the 14-day time-scale as good because it provides enough time for taking appropriate decisions for crops and livestock management and disaster preparedness (Figure 4.6). It should be noted that some farmers (29%) consider the 14-day lead-time as too long for many purposes when the weather conditions may change in between and thus they rely mostly on the 7-day forecast. Currently, a few farmers uptake seasonal forecasts in agricultural decision-making. However, farmers have trust in seasonal forecast information, mainly for planning reasoning. The final meetings revealed that the seasonal forecast indicated the wetter or drier season compared to the average conditions and perception about the seasonal forecast.

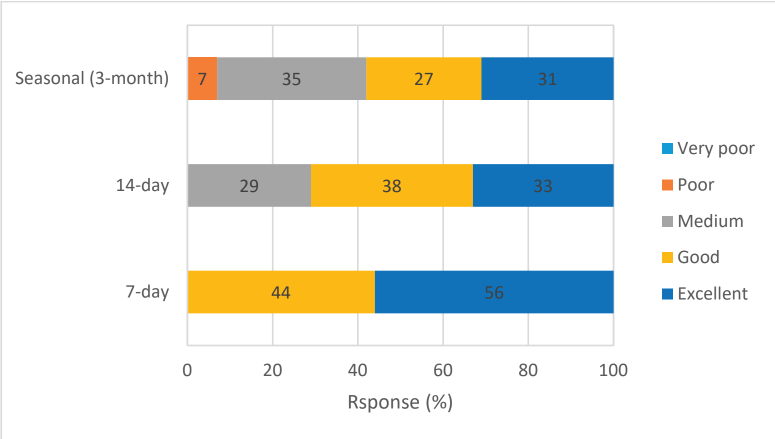


Figure 4.6. Farmers' perception of the seasonal, 14-day, and 7-day forecasts quality for agricultural decision-making in the lower Bengal Delta. Five points (excellent, good, medium, poor, and very poor) Likert scale were applied to evaluate the quality of forecasts.

4.3.3.3 Attributes of communication and forecast uptake

We evaluated several attributes of communication that indicate an increased forecast uptake. Farmers reported an increased uptake of the forecast information due to improved capacity, information quality (accuracy) and services, time-specificity, flexibility to access information, and communication modes (Figures 4.7). Since the co-production process initiation, farmers and the local extension officers were weekly engaged at FFS. This engagement process involved farmers' capacity building in acquiring knowledge on forecasts, interpretation skills, and usage through frequent interaction and information services. The local extension officers and farmers co-developed weekly and bi-weekly crop advisory during the weekly interactions that led to better forecast uptake and advisory services jointly with farmers and extension officers during the co-production process. 64% of the farmers perceived the quality of forecast service as excellent, while 33% of farmers perceived it as useful. The majority of farmers (73%) appreciated the flexibility in the deliberation of forecasts using different communication modes. The farmers highly value feedback because it offers a comparison with local observation and the shared forecasts. About 20% of farmers often share forecasts with peers and relatives for agricultural decision-making. Farmers acknowledge the researchers' positive role and extension officers for forecast communication, explanation, and interpretation during the co-production process.

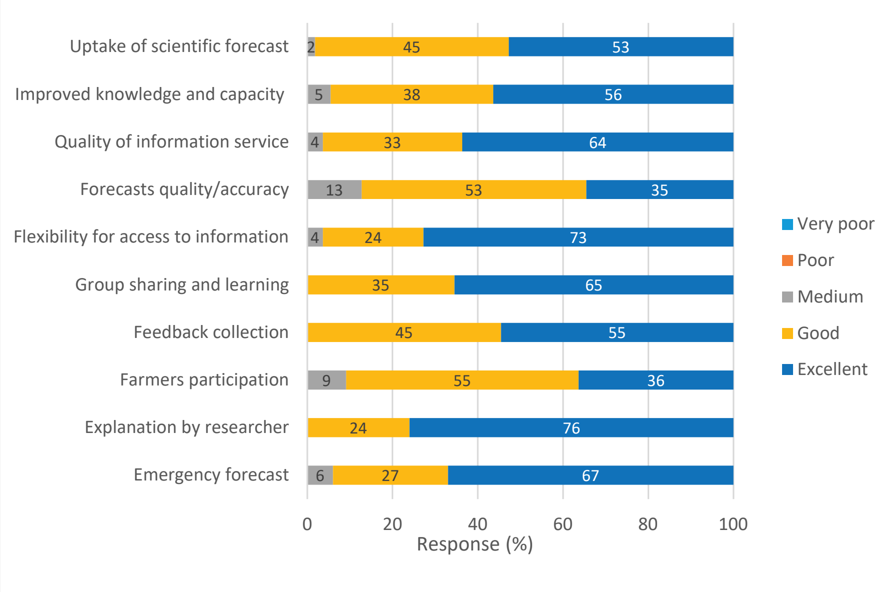


Figure 4.7. Farmers' perception of various forecast communication attributes that were evaluated through farmers' engagement at farmer field schools. Five points (excellent, good, medium, poor, and very poor) Likert scale were applied to evaluate various forecast communication attributes.

4.3.4 How forecasts visualization and communication support decision-making

Results show that farmers have changed several tactical and strategic decisions such as the date for seedbed preparation, transplantation, fertilizer and pesticide application, weeding, labour-hire, crop harvest, drying, and crop processing, based on the received forecasts. Farmers reported that these decisions have resulted in positive financial outcomes. The weather forecasts have helped smallholders in the optimum application and timing of inputs to crop-fields. About half of them perceived a 25-50% reduction in fertilizer and pesticide costs, as well as reduced crop damages. Farmers discussed the optimum application and timing of inputs based on forecast information in weekly interaction meetings with peers and local extension officers. Reduced use of fertilizers and pesticides can potentially have significant positive environmental outcomes and increase the profitability of the cropping systems. Besides, farmers also made several tactical decisions for the management of their fish-ponds (aquaculture) such as placing nets to prevent fish migration during heavy storm events, additional slat input in small-scale shrimp ponds to maintain salinity level during heavy rainfall, placing an air pump to tackle extreme temperature and heatstroke of shrimp and repair and maintenance of embankment surrounding fish-ponds. These have economic outcomes from improved management and agricultural decision-making.

Besides, adapting their decision for the rice cropping systems farmers also adapted several livestock management decisions based on understanding and trust in visual forecast diagrams and communication. For example, farmers did not allow livestock to natural grazing fields if there was a forecast for an extreme weather event such as heavy rainfall, thunderstorm, and cyclones. Also, they collect additional fodder for livestock from the fields in these situations. Since our field study's inauguration, farmers in Khulna faced three extreme weather events: Cyclone Fani in May 2019 and Cyclone Bulbul in November 2019, and heavy winter rainfall in January 2020. We widely disseminated these cyclones and extreme rainfall forecasts among local extension officers and farmers in the study area. Our forecasts for these extreme weather events were communicated earlier than those of the national meteorological department. Early communication gave the farmers a longer time-period to prepare for the cyclones, resulting in reduced losses and damage to their households, livestock, aquaculture ponds, and farm assets. During interviews, the farmers also indicated that they used the advanced cyclones forecasts to inform relatives about the emergency, repair households, livestock sheds, cutting tree branches above their roofs, and did not allow livestock to graze in the open field. They also collected additional fodder for their cows and bought emergency household needs and dry foods to prepare for the cyclone. This shows the value of the longer-term forecast of cyclones in the region.

Rainfall in winter is not very common in Bangladesh. Farmers involved in our study received a 1- and 2-week advance forecast for a moderate to heavy winter rainfall event at the beginning of January 2020. Based on the forecast farmers were able to successfully harvest and collect their ready paddy from the fields before the heavy winter rainfall started. We observed that farmers collected their harvested paddy from the field from early morning until late in the evening up to 10 pm using family labors. We interviewed several farmers at that time and found that farmers did not want to leave their harvested paddy at the field, showing their trust in the forecast shared through field schools. Several farmers commented that this is the first time in their life that they were collecting paddy at night from the fields.

Also, we observed that the farmers use the 7-day and 14-day forecasts for many non-agricultural decisions such as travel plans scheduling cultural programs, and social gatherings. We observed that female farmers follow forecasts more frequently than male farmers in daily decision-making concerning drying crops and fuel-wood, food processing, seeds processing, dung-stick making, compost preparation, and livestock management.

It has been observed that farmers frequently accessed forecasts shared through FFS. This reduced their dependence on traditional climate information sources such as peers, radio, television, and newspaper significantly. About one-third of farmers still follow forecasts from television, and some farmers follow forecasts from the radio. The farmers have more trust and confidence in the quality of forecasts shared through the FFS platform than that of the traditional sources (Figure 4.8).

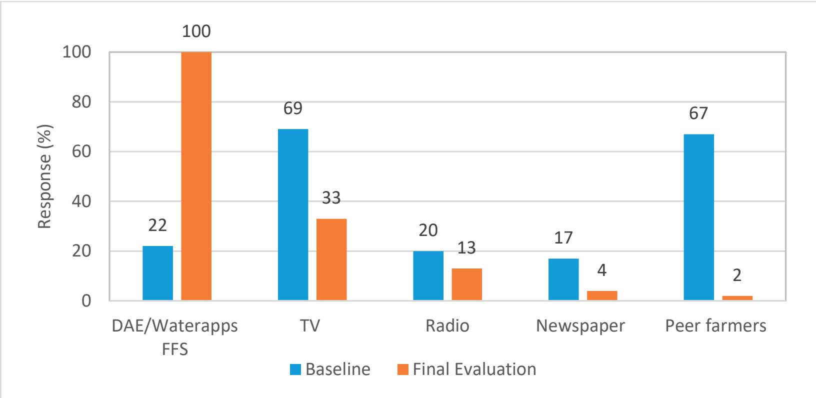


Figure 4.8. Farmers' preference of various climate information platforms/services during baseline (blue) and final evaluation assessment (orange).

About 95% of the FFS farmers followed the scientific forecasts because they were perceived as more reliable and applicable for decision-making. The young farmers also indicated limited or no trust and personal skills in traditional knowledge-based forecasts. Therefore, young farmers do not consider traditional forecasts in their agricultural decision-making. Some previous studies showed that the combined use of scientific and traditional forecasts might lead to better agricultural decision-making (c.f. Gbangou et al., 2020b, Zuma-Netshiukhwi et al., 2013). Results from his study, however, indicate that when having better access to scientific forecasts, 73% of farmers do not combine the scientific and traditional forecasts for making agricultural decisions-. About 27% of farmers do see a value in using both scientific and traditional forecasts. The older farmers especially used both scientific and traditional. However, during the baseline study, we observed that farmers mostly followed their personal experience and traditional knowledge-based forecasts for agricultural planning and decision-making (Figure 4.9).

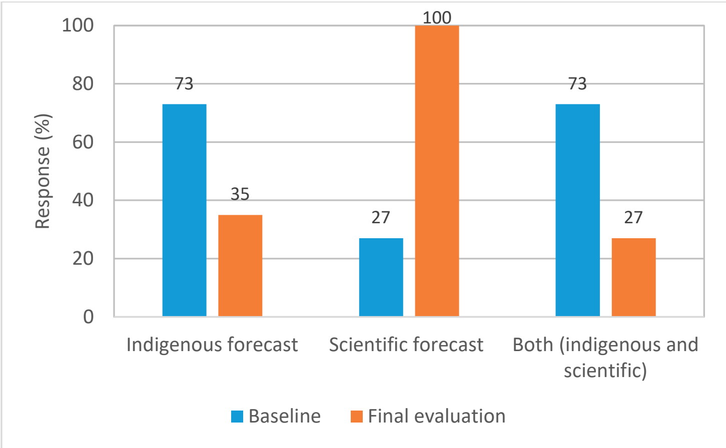


Figure 4.9. Farmers' usage preferences of indigenous, scientific, and/or combined weather forecast information for agricultural decision-making in the Lower Bengal Delta.

4.4 Discussion

4.4.1 How co-production support smallholders' decision-making

Climate information services can reduce vulnerability to hydroclimatic risks (Roy and Alam, 2020, Kumar et al., 2020b, Hansen et al., 2011). This study provides empirical evidence of how co-production of climate information services and how visualization and communication enable farmers' forecast uptake to manage crop production and reduce input costs. This indicates the power of co-developing climate information services with and for smallholder farmers (Bremer et al., 2019, Christel et al., 2018). Capacity building of farmers at FFS played an important role in improved uptake of forecast information by the smallholders. Through capacity-building efforts, farmers acquired skills that led to a better understanding and communication of forecasts that bridged the gap between researchers and farmers (c.f. Christel et al., 2018). The local agricultural extension officers also played an important role in the co-production of agricultural advisory services with farmers during weekly interaction meetings. We engaged local extension officers in the co-production process, as they are the responsible governmental authority for agricultural advisory services in Bangladesh and act as broker for agrometeorological information services to local farmers. Thus, without their involvement and cooperation, a co-production process will probably not be effective and feasible in the study area. The local extension officers also can facilitate translation of the forecast information services locally with and for farmers beyond a project intervention.

The frequency of forecast use is related to forecast quality, understanding and trust, timely communication, and farmers' capacity to act on forecast information. Experimental farmers currently use weather forecasts information more frequently after the initiation of service co-production for agricultural and non-agricultural decision-making. The young generation of farmers is more used to receiving updates and communicating the forecast information to fellow farmers using messenger-app and personal interactions (Gbangou et al., 2020a). This suggests that a bottom-up co-production approach has increased forecast uptake by smallholders followed by capacity building and frequent communication (Kolstad et al., 2019).

Co-production of climate services should start with quality forecasts, and building awareness, capacity, and trust of the farmers (Agyekumhene et al., 2020). Capacity-building efforts will lead to better services co-production through climate scientists and farmers (Gbangou et al., 2020a). This will ensure collaboration among climate scientists, local extension service, and farmers for governance and operational nexus of climate services (Vedeld et al., 2019, Bremer et al., 2019, Lemos and Morehouse, 2005). Indeed, usefulness and usability are the key indicators for effective services (Hewitt et al., 2017). Farmers said that they did not rely much on the visual forecast diagrams shared through different modes of communication in the beginning. However, training and frequent interactions acquainted farmers with the purpose of visual forecast diagrams and their usage. The iterative training on forecast diagrams, interpretation techniques, and discussion on (in)accuracy or uncertainty and the probability of forecasts built farmers' confidence in the forecasts. This improved trust of the farmers' in the forecasts and facilitated the uptake in climate-sensitive decision-making.

According to Kruk et al. (2017), co-production encourages mutual learning to frame climate information services in decision-making. A bottom-up co-production approach used in this study confirms that the farmers, extension officers, and researchers' mutual learning have improved understanding of farmers' information needs, decision process, and time-scale needed to influence decision-making. For example, co-learning helped to identify changes in information needs over time and capacity building. Besides, co-learning with smallholders unfolded that seasonal forecast was not very fruitful for the smallholders because they mostly follow traditional cropping practices considering an average year of hydroclimatic prediction combined with limited interannual climate variability in Bangladesh (Kumar et al., 2020b). Farmers perceive the importance of seasonal forecast, preferably 1-month ahead of the crop seasons. The seasonal forecast can help farmers and local extension officers advance field precautions and forecast-based advisory services at the local level. We conclude that the co-learning process expanded forecast dissemination and usage among experimental farmers and peers. Also, the majority of farmers continuously shared forecasts with peer farmers, family members, and other relatives. During qualitative interviews and meetings, about 90% of farmers reported that at the starting of the co-production process they had no trust in 7-day, 14-day, and seasonal forecasts. This was also when experimental farmers initially received criticism from peers on days when forecast information was inaccurate.

These results indicate that capacity, trust-building, and understanding forecast uncertainty (inaccuracy) are important issues to be addressed during the co-production process. Forecast users are not to be traded to understand and deal with climate information uncertainty through iterative interactions and offering participatory training (Nyadzi et al., 2019, Peterson et al., 2010, Daly and Dessai, 2018). In the current study, the bottom-up co-production process with farmers builds know-how and confidence among local farmers for informed decision-making. Therefore, we conclude that building trust between service developers and user communities is an important co-production outcome with users.

4.4.2 Capacity building for farmers and local extension officers

Integrating climate service with capacity building of farmers and extension officers can be an important tool in building adaptive capacity and reducing farmers' climate risks (Roy and Alam, 2020, Cliffe et al., 2016, Kumar et al., 2020a). During this study, we built smallholder farmers' and local extension officers' capacity towards better understanding and interpretation of forecasts diagrams through visualization and communication. This improved the extension officers' knowledge base for advisory services based on forecasts (Zuma-Netshiukhwi et al., 2013). During weekly interaction meetings, the extension officers participated in co-developing advisory services with farmers by taking part in the decision-making process. This eventually improved forecast understanding and trust of farmers in forecast information and services. The capacity building, however, was not a straightforward and easy task in the co-production process. It was an iterative and continuous effort that required ICT tools support for farmers and extension officers, and multiple communication modes. In the beginning, about half of the farmers had access to a smartphone. Also, the local extension officers had no training for providing climate information services using a smartphone. Therefore, most of the farmers had no experience using a smartphone, internet, and mobile application for agricultural decision-making. As ICT-led communication services have the potential for timely delivery of information services (Hansen et al., 2011), we provided ICT tool support to farmers for conducting training and group learning during co-production.

The result shows that ICT-provision inspired farmers to adopt ICT-led information access and services quickly. More importantly, our evaluation results indicate that all farmers take up information from FFS and the majority of the farmers (71%) had access to smartphones at the end of the experiment compared to 54% at the start of the study (54%). The trained extension officers currently have their virtual farmers groups for providing climate information and crop advisory services. This indicates that the co-production effort encouraged farmers and local extension officers to use smartphone applications to access weather and climate forecasts. Furthermore, through participatory interactions, farmers gained a better understanding of climate variability and how climate change affects their agriculture and livelihood practices in the entire delta.

Dealing with forecast uncertainty was also evaluated by farmers positively. They mentioned that they had no prior knowledge about forecast uncertainty. However, during the co-production process, both farmers and extension officers learned that this is one of the most important concepts as well as understating how to use probabilistic forecasts for decision-making. A better understanding of the forecast uncertainty through probability percentages in the visual diagrams gained farmers and extension officers confidence in forecast accuracy. Finally, the co-production through forecast visualization and modes of communication significantly contributed to changing the farmers' behaviour and attitude toward risk-based decision-making. This will eventually contribute to the climate-resilient agricultural practices of the farmers in the Lower Bengal Delta.

4.4.3 Value of co-production with farmers

The value of climate services depends on information quality, understanding, timely communication, and use to improve decision-making, crop yield, and economic benefits. To assess such value Tall et al. (2018) and Gbangou et al. (2020a) indicated that climate service monitoring and evaluation remains a significant challenge. Evaluation studies that track outcomes (change in decisions) and impacts (long-term perspective) at the household or farm level are limited so far. Thus, we addressed the value of co-production through qualitative and quantitative responses of farmers in an experimental setup over a crop season.

We observed farmers' participation and forecast uptake to be very high (>90%) in the study area once it was co-produced through iterative face-to-face interactions followed by training and involving the governmental local extension officers who are in regular contact for all types of agricultural extension services. Higher participation during co-production probably indicates an urgent need and usefulness of the forecast services supplied through farmer field schools. Farmers reported that based on participatory learning and information services, they could make better decisions than the decisions based on average years' perception of climatic prediction.

The smallholders of the Lower Bengal Delta are living in a vulnerable environmental setting (Shameem et al., 2014, Huq et al., 2015). Thus, climate information service is critical to support smallholders to improve agriculture and livelihoods practices. Although the climate information services were developed with the aim to support smallholders' agricultural decision-making, we observed that the forecast information was also used for non-agricultural decision-making. The farmers also used the information to prepare for extreme events such as cyclones. The 7- and 14-day forecasts helped the farmers reduce damage to their crops, livestock, households, and aquaculture ponds. During interviews, farmers indicated that the met-office disseminated forecasts about these extreme weather events only 1-3 days ahead, which does not give the farmers enough time to protect their crops, household, and livestock. The longer 7- and 14-day forecasts allowed the farmers to be better prepared and reduce damages and financially during cyclones and heavy rainfall events. This shows the added value of giving farmers access and trust in long-term weather forecasts to manage climate variability and extreme events.

These informed decisions resulted in improved socio-economic and livelihood outcomes for farmers during qualitative interviews and participatory meetings by farmers. Managing disaster risks was the most important benefit reported by all farmers during interviews and final meetings. Notably, based on the short-term (7-day) forecast information female farmers organized their agricultural and household jobs more precisely and timely. Some female farmers at *Sanchibunia* village also reported that they used forecast information for vermin compost preparation, storage, and harvest. All these multi-dimensional benefits and co-benefits finally motivated farmers and the local extension officers to model a virtual platform *'Farmers Weather Club'* in Batiaghata, Khulna, Bangladesh.

4.5 Conclusion

Our results indicate that the co-production of information services improves the uptake of weather and climate information and results in a wider sharing of climate information for agricultural decision-making. A co-production process improves farmers' aptitude to take up probabilistic forecast information. Farmers reported a better understanding and acceptance of forecast uncertainty once they received training and capacity building on the probabilistic forecast. The co-production at the farmer field schools improved smallholders' interpretation skills and capacity through frequent interaction and training. This improved the farmers’ understanding and trust of the forecast, and farmers now take several tactical and strategic crop decisions based on probabilistic forecasts.

Local farmers in Southwest Bangladesh face numerous social, economic, technical, technological, and personal challenges. A participatory co-production process offers the opportunity to address these challenges through frequent farmers’ interaction and capacity building. In this regard, the local agricultural extension department could play a vital role in farmers’ training and development of advisory services using farmer field schools based on forecast information. The local extension officers' capacity building is an important integrated part of successful co-production, which could lead to better uptake and continuation of information and advisory services beyond a project period.

We found that co-production of climate service has several co-benefits. The co-production helps farmers in several non-agricultural decision-making by following the 7- and 14-day weather forecasts. Besides, using the short-term forecast (7-day) women farmers organized their daily farm and household activities more precisely and in a timely fashion. Most importantly, the forecasts for the cyclones and heavy winter rainfall helped the farmers better prepare for these events, resulting in reduced losses on the crop, livestock, and limited damages to households and farm assets.

The co-production offers feedback collection about forecasts and their success from users. This is important to adjust the co-production process for improving information services and uptake in a local context. Finally, we conclude that the co-production with smallholders resulted in wider sharing, dissemination, and scientific forecast uptake for smallholders' climate-sensitive decision-making in the Lower Bengal Delta. It has reduced farmers’ dependency on traditional forecasts by improving scientific forecast uptake and better preparation for extreme weather events.

Chapter 5

Are farmers willing to pay for participatory climate information services? Insights from a case study in the peri-urban area of Khulna, Bangladesh

Chapter 5

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Abstract

Location and time-specific weather and climate information for agriculture is vital for productive and sustainable food production. Participatory climate information services that are being co-developed in the Lower Ganges Delta in Bangladesh have the potential to address farmers' needs and assist them with climate-sensitive decision-making. The main purpose of this study is to assess how willing smallholder farmers are to pay for weather and climate information services that are being co-developed in Khulna, Bangladesh, and what are the motivational factors affecting farmers' willingness to pay (WTP). A double-bounded dichotomous contingent valuation method was employed to estimate the farmers' willingness to pay (WTP) for participatory climate information services. The results indicate that on average, around 80% of the farmers are willing to invest in tailor-made information services. Farmers who had received initial training and participated in the co-development of the services have a higher willingness to pay which shows the need for initial year promotional free services to develop markets for such services. The main driving factor that influences the farmers' willingness to pay for the services is the estimated cost of the service. Nevertheless, the experiment shows that the commercial potential of the participatory services is high. The climate information services to small farmers in peri-urban deltaic areas in Bangladesh can prove to be vital services for adaptive and sustainable agriculture and a major contributor to climate resilience.

Keywords: *Climate information services, peri-urban agriculture, willingness-to-pay, double-bounded dichotomous contingent valuation method, Bangladesh*

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Practical implications

In the peri-urban areas in urbanizing deltas of the world, farmers face challenges in crop production due to the increased hydroclimatic variability as a result of climate change. These challenges are often attributed to poor understanding of climate variability in combination with little or no access to meaningful weather and climate information that affect farmers' decision-making and result in negative socio-economic implications.

The WATERAPPS project is active in the urbanizing Lower Ganges Delta and co-develops with and for farmers weather and climate information services to improve food security and contribute towards sustainable agriculture. In the peri-urban area of Khulna city in Bangladesh, Farmers' Field Schools (FFS) were initiated where farmers are co-developing climate information services and simultaneously building their adaptive capacity towards hydroclimatic phenomena and extremes. The participants of the FFS were engaged weekly throughout the Kharif-II season (mid-May to mid-October) in 2019. During the face-to-face interaction with the FFS participants, the tasks included discussion and elaboration on weekly forecast followed by the participatory design of agricultural information, together with local officers from the Agricultural Extension Office (DAE) that showed very active participation in the experiment. By the end of the experiment, the willingness of farmers to pay for participatory weather and climate information services was assessed, using a variety of socio-economic factors that could potentially influence farmers' WTP such as whether or not have received training, the provisioned value of the Climate Information Service (CIS) as well as age, gender, education, family and farm size. To study the implications of participatory co-development of the services, the research also included a control group site where participants had not received prior training nor had participated in the FFS.

The outcomes of the Double-Bounded Contingent Valuation Method (DB-CVM) indicated that on average more than 80% of the participants in the study are willing to pay for tailor-made climate information services. The provisioned value of the CIS is the main driving factor, followed by whether or not the farmers have received training and capacity building on weather and climate-related phenomena. 90% of the study site participants answered that they were willing to pay for the participatory services, while 75% of the control site indicated that they are also willing to invest in tailor-made weather and climate information services for sustainable agriculture.

The high percentage of people from both groups that are willing to invest in CIS in combination with the active engagement of the DAE officers during the FFS that showed an active interest for services upscaling indicate that there is a need for risk-reducing mechanisms at various administrative levels that could assist farmers to increase their adaptive capacity and resilience against weather extremes, concerning agriculture. Provided that the amount of people in Bangladesh that are related to agricultural activities exceeds 100 million, it indicates the existence of potentially huge market size. Thus, tailor-made weather and climate information services have the opportunity to be co-developed, finetuned, and/or implemented that could play a vital role towards mitigating the risk associated with farming activities and enhance the climate resilience of Bangladesh's agriculture.

In this direction, governmental organizations such as the Agricultural Extension Office (DAE) could invest in these services to make them more affordable for small farmers. Alternatively, the Bangladeshi government could subsidize these services which would help create a market that will boost social entrepreneurship and will promote private entities towards investing in tailor-made climate information services that could provide vital information and contribute towards sustainable agriculture.

5.1 Introduction

Climate is a key driver for all ecological and economic systems Steiner et al. (2018), (Pachauri et al., 2014) and thus an important factor on agricultural productivity, the efficiency of crop production, farmland value, and net farm income (Hossain et al., 2020, Arshad et al., 2017, Chatzopoulos and Lippert, 2015, Moore and Lobell, 2014, Massetti and Mendelsohn, 2011, Kurukulasuriya and Ajwad, 2007). Nevertheless, increasing evidence shows that climate is changing and this affects many sectors with agriculture being one of the most sensitive ones concerning climate change impacts (Ahmed et al., 2015, Davidson et al., 2019). Climate change directly or indirectly affects the socio-economic sustainability of smallholder farmers including crop failures, increased production costs, reduction in farmer income, and increase in the seasonal unemployment rate (Masud et al., 2017, Banna et al., 2016, Siwar et al., 2009). Many scholars mention that developing nations are more prone to climatic effects due to the nature of the impact on the agro-economy (Al-Amin et al., 2020). Climate change mitigation and adaptation approaches are crucial to offsetting the overall impacts and in this direction creation of scientific climate information as well as translating and transferring that knowledge to farmers to improve their decision making can enhance millions of lives in farming areas of developing countries who are exposed to vagaries of climate. Climate Information Services can be employed to guide adaptation practices towards climate change effects and assist agricultural development, especially in countries whose economies depend on rain-fed agricultural systems (Antwi-Agyei et al., 2020, Vaughan et al., 2019a, Singh et al., 2018). Climate information services hence can take a leading and vital role in agricultural decision making since it can help farmers make adaptive farm decisions that could lead to enhanced economic benefits and reduced economic losses (Tall et al., 2018, Muema et al., 2018, Dayamba et al., 2018, Vaughan et al., 2017, Coulibaly et al., 2015b, Vermeulen et al., 2012, Jagtap et al., 2002).

To develop effective services, ensuring multi-way communication of knowledge to tailor information services to the needs of the users (Vedeld et al., 2019) i.e. co-designing is a powerful approach. Co-design approaches allow local farmers to be involved in the co-development of climate information services for adaptive agricultural decision-making. In this direction, the WATERAPPS project was initiated in 2016 to co-develop tailor-made climate information services to improve food security and sustainable agriculture (Gbangou et al., 2020b, Sarku et al., 2020a, Kumar et al., 2020a, Kumar et al., 2020b) in peri-urban areas in the urbanizing deltas of Ghana and Bangladesh. The project follows a co-designing approach aiming at achieving its goals by: 1) combining mobile information technology with the latest insights on knowledge sharing, 2) integrating scientific with local forecasting knowledge to improve weather predictability, and 3) attuning knowledge about adaptive decision making through farmers' capacity building towards weather and climate-related phenomena. Within the scope of the WATERAPPS activities in Bangladesh, Farmers' Field Schools (FFS) were organized at two communities in the peri-urban area of Khulna (research location) for the monsoon rainfed season (mid-May to mid-October known as Aman season). Co-design and knowledge co-production approaches were adopted because they offer a great opportunity for the construction of useful and usable climate information which is increasingly occurring in developing countries (Vincent et al., 2018).

The study focuses on the Bangladesh case in the Lower Ganges Delta in the south-west of Bangladesh, which is an ecologically rich and highly productive agriculture area, where location and time-specific information is crucial for agricultural decision-making (Kumar et al., 2020b). Farmers in the peri-urban areas of the Ganges Delta are mainly based on traditional practices (e.g. traditional calendars, beliefs) to make their weather and climate-related agricultural decisions (Ali et al., 2016, Rahman and Alam, 2016, Lebel, 2013, Chaudhury et al., 2012, Morshed, 2007). However, increased hydroclimatic variability that governs the region (Mondol et al., 2018a, Al-Mamun et al., 2018, Islam, 2016, Islam and Hasan, 2016, Huq et al., 2015, Shahid, 2010, Shahid, 2011, Mirza, 2002) as a result of climate change, as well as monsoon rainfall variability (Ahasan et al., 2010, Hoque et al., 2011) in combination with the poor or lack of quality of available hydroclimatic information, exerts severe socio-economic and environmental impacts on farmers. As a result, in the peri-urban areas of Khulna, Bangladesh, farmers face risks associated with severe waterlogging, drought conditions, storms, and salinity intrusion (Hasan et al., 2018, Mondal et al., 2013, Rahman et al., 2011, Shahid and Behrawan, 2008, Gain et al., 2007). Thus, well-defined and tailor-made weather and climate information services have the potential to become a more adequate risk assessment tool for the rural-farm households in the Lower Ganges Delta of Bangladesh. It is more important in the backdrop that agriculture and food security in Bangladesh is expected to become more vulnerable to climatic extreme events and increase in temperature and rainfall variability, given the projected global increase in CO_2 levels, according to the Intergovernmental Panel on Climate Change (Pachauri et al., 2014).

Climate information services are recognized as a powerful tool to reduce the effect of risks associated with weather and climate as they can increase the resilience and the adaptive capacity of farmers (Ouédraogo et al., 2018). Despite the importance of climate information services in Bangladesh, very few studies have assessed the farmers' willingness to invest in services that could provide tailor-made information and help them prepare and take more informed and adaptive decisions, minimize losses and increase their economic output. A farmers' relative willingness to pay (WTP) for participatory climate information services may vary depending on their socio-economic status and other motivational factors (Al-Amin et al., 2020, Ahmed et al., 2015). Identifying the influence of these factors along with what kind of information farmers would be willing to pay for could guide the efficient delivery of effective climate information services (Vincent et al., 2020c). Given this research void, we provided experimental access to climate information services co-design with local farmers of Batiaghata sub-district of Khulna and we subsequently assessed their willingness to pay for the participatory provided services in the study area. For a comparative assessment, willingness to pay for climate services of farmers in a control site was also assessed. For this purpose, a farm-household survey was conducted during the Khariff-II or Aman season (mid-May to mid-October 2019) to estimate the farmers' willingness to pay for the provided (and envisioned) climate information services that are co-developed in the peri-urban communities in Khulna, Bangladesh. This study (i) assesses the farmers' willingness to pay (WTP) for the participatory climate services in peri-urban Khulna and (ii) determines the factors that influence their WTP.

5.2 Material and Methods

5.2.1 Study area general characteristics

The study area is located in the south-west coastal region of Bangladesh. Geomorphologically, it lies in the lower part of the Ganges Delta located in the Khulna district. The city of Khulna is the third-largest metropolitan city of Bangladesh and the capital of the Khulna division. The city is surrounded by the rivers of Rupsa, Bhairab, Pasur, Hatia, and Mayur (Roy et al., 2005) and has a tropical savanna climate (Beck et al., 2018, Peel et al., 2007). The summer period receives plenty of rainfall, while during the winter there is very little. According to the climatological analysis of Kumar et al. (2020b), mean annual precipitation is 1752mm, mean annual air temperature is 26,7°C and both present a significant increasing trend during the period 1948-2018. Topography and local climate provide ideal conditions for peri-urban agriculture and constitute Khulna as a regional food production hub. Agricultural lands in this area are highly influenced by tidal inundation being located in the active and low-lying coastal part of the lower Ganges delta. The farming communities of this zone are vulnerable to disasters as a result of climate change and especially around Khulna, the farmers have been facing increased challenges that threaten the food and livelihood security (Huq et al., 2015, Afroz and Alam, 2013). They have identified monsoon rainfall patterns, river discharge, and tidal characteristics, salinity intrusion in soils, temperature stresses, and weather extremes such as thunderstorms and cyclones as the major threats to their agricultural livelihoods (Kumar et al., 2020b). Besides that, in the last 15 years alone, farmers in the region have experienced the devastating socio-economic effects of cyclones Sidr in 2007, Aila in 2009, and Bulbul in 2019, and Amphan in May 2020. All these disasters have had remarkable impacts in Bangladesh in general as thousands of lives were lost while the damages were estimated to millions (Islam et al., 2017, Ahmed et al., 2016).

5.2.2 Experimental design

The study was conducted in the peri-urban area of Khulna within the scope of the WATERAPPS project by selecting an experimental (study site) farmers' groups (n=52) and a non-experimental (control site) farmers' groups (n=59) in Batiaghata sub-district that had similar geographical and agricultural characteristics. Figure 5.1 shows the location of the study site communities that are located in the peri-urban area of Khulna city. Two Farmer Field Schools (FFS) at *Basurabad* and *Sanchubunia* villages (study sites) were established for the crop season Kharif-II (mid-May to mid-October) in 2019. The participants of the study sites had also received prior training from the Participatory Integrated Climate Service for Agriculture (PICSA) (Dorward et al., 2015). PICSA training is focusing on not just providing locally appropriate climate information, but engaging and training farmers to better understand and use the information in their farming decisions. Following the PICSA training where the study site farmers expressed their weather and climate information needs, we engaged with the 52 farmers weekly throughout the Kharif-II season and provided meteoblue[2] forecast for 7-, 14-days and seasonal (3 months) weather forecasts as well as training on its interpretation and advisory services with the help of the local agricultural extension department

[2] https://www.meteoblue.com

(DAE). Figures 5.2-5.4 present an example of the provided meteoblue forecast. Three kinds of face-to-face interaction were provided through the FFS: 1) general discussion and comments on the weekly provided forecast information (7-, 14-days and 3 months); 2) group learning through elaboration and discussion on the forecasts; and 3) agricultural advisory and decision-making based on the forecasts in a participatory fashion with the experts from local agricultural extension department. The control site farmers were selected from *Fultala* and *Mathavanga* villages of the same sub-district where no FFS activities were organized.

The study site farmers used the provided forecast as well as the generated weekly agro-meteorological advice during all farm activities and growing stages. This included land and seedling preparation and also hiring labor which was proven to be challenging the previous years as in many cases farmers were investing in hiring personnel who was eventually unable to work due to extreme weather phenomena. Moreover, activities included regulating farm water levels as well as the timing of fertilizer and pesticide application which was also proven to be challenging the last years as farmers since they had no prior information they often used to fertilize more times than normal which was resulting in economic losses besides environmental impacts. Towards the end of the cropping season, farmers received information and planned their harvesting time depending on their cultivation as well as the processing and storage of the products, and in some cases, farmers reported that the tailor-made information helped them secure their product and its quality. Finally, some of the farmers also reported that they used the co-developed weather and climate information to align their harvesting and processing with the market.

Following the completion of the FFS in the study site, we assessed the farmers' willingness to pay for climate information services in both research sites by employing a disproportionate random sampling technique to accomplish a representative number of samples from the control and study sites' participants. The survey questionnaires were divided into three sub-sections: (1) personal information, (2) socio-economic information, and (3) double-bounded dichotomous choice contingent valuation questions. The digital survey tool Kobotoolbox was used during February 2020 to conduct the research and fill out the survey questionnaires through face-to-face interactions with the participants. The survey questionnaires can be found in Supplementary Materials 5A.

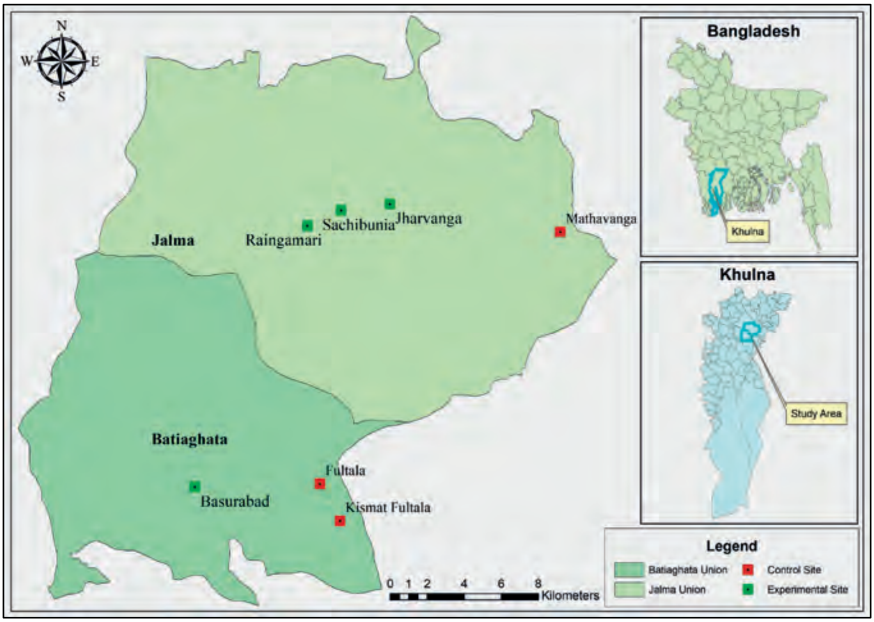

Figure 5.1. General Location of the study area and the farming communities

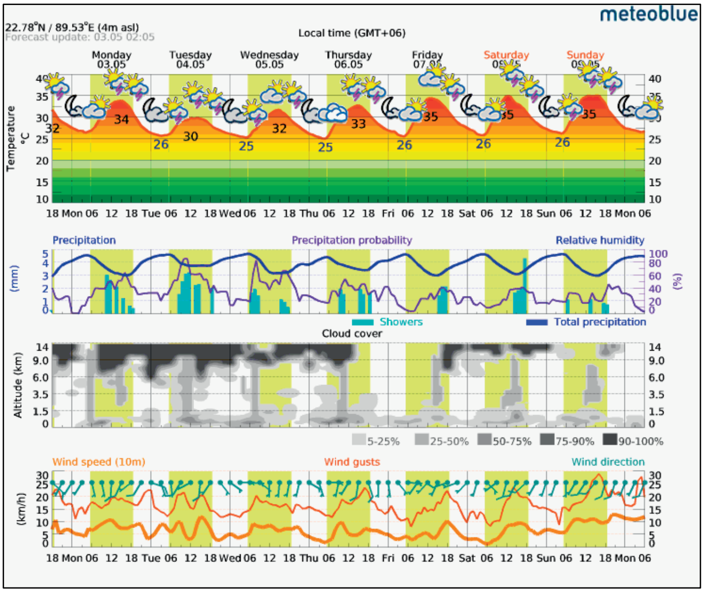

Figure 5.2. An example of a 7-day forecast provided by Meteoblue.

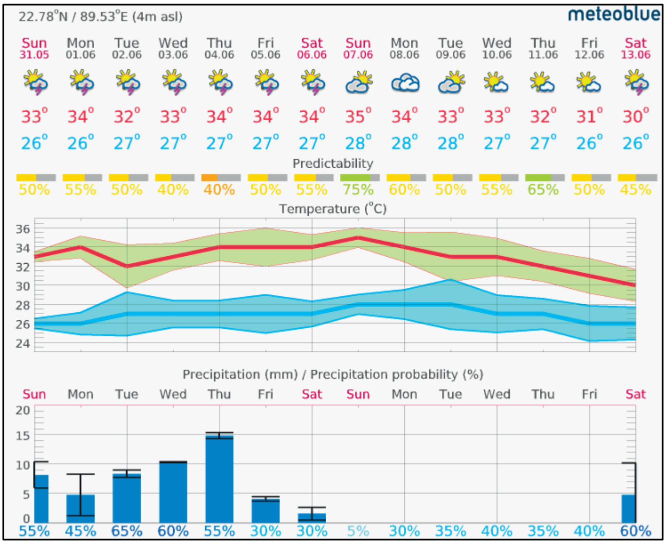

Figure 5.3. An example of a 14-day forecast provided by Meteoblue.

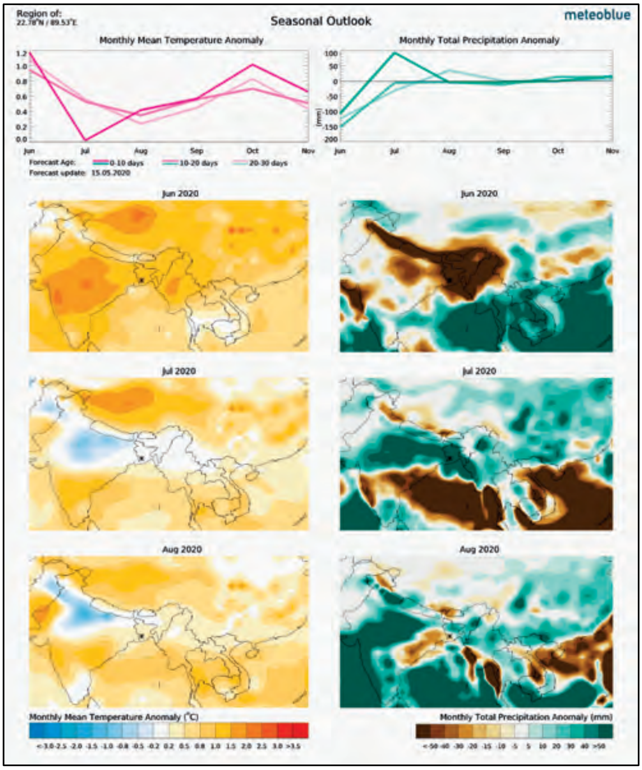

Figure 5.4. An example of a seasonal forecast provided by Meteoblue.

5.2.3 Contingent valuation method to assess farmers' willingness-to-pay

To assess the Farmers' Willingness to Pay for CIS, a hypothetical market was developed using the CVM method. The methods that could be employed in this case to assess the WTP include the contingent valuation method (CVM) and the choice modeling (CM) method. CVM is one of the preferred methods for estimating the willingness to pay of non-easily marketed environmental goods and services around the world (Ouédraogo et al., 2018, Fonta et al., 2018, Amegnaglo et al., 2017, Arshad et al., 2016, Mabe et al., 2014, Sarkhel and Banerjee, 2010, Akter et al., 2009, Fuks and Chatterjee, 2008, Akter, 2006, Ahmed et al., 2015, Banna et al., 2016, Al-Amin et al., 2020). In this study, the CVM method was selected to be used also because it is relatively easy to execute given the education as well as the understanding capacity of local farmers (Arshad et al., 2016, Markantonis et al., 2012, Jin et al., 2006) although Jin et al. (2006) concluded that both methods may be effective in assessing willingness to pay under hypothetical market situations. Amongst the CVM approaches that have been proposed in literature such as the single-bounded dichotomous choice (SBDC), double-bounded dichotomous choice (DBDC) open-ended CVM, or stochastic payment card design (e.g.Fonta et al., 2010), we used the DBDC, given the limited number of participants in the experiment and DBDC's better performance in estimating willingness to pay estimates within tighter confidence intervals, even when the sample sizes are smaller (Hanemann et al., 1991).

The DBDC model consists of two WTP questions both of which can be answered with a 'YES' or 'NO'. In each question, respondents are faced with a bid amount that is willing to pay for participatory climate information services. Responses of 'NO' to that bid amount are followed up with a lower amount, while 'YES' responses are followed up with a higher amount (Winden et al., 2018). Table 1 presents the bid amounts that were used in this study. The initial bid amounts were 20Tk, 40Tk, 100Tk. The subsequent bid amounts offered were half the initial amount for respondents who answered 'NO' and twice the initial amount for those who answered 'YES'. Consequently, the follow-up lower or higher amounts were offered depending on which initial bid the respondent received.

Table 5.1: Bid structures (in BDT) that were used in the current study (USD in parentheses)

Initial bid value (BDT)	Follow-up lower bid (BDT)	Follow-up higher bid (BDT)
20	10	40
40	20	80
100	50	200

The willingness to pay bids were pre-designed and assigned randomly across the participants of the FFS such that approximately one-third of the sample started with 20 Tk. 40 Tk. and 100 Tk.

respectively, to avoid starting-point bias (Mitchell et al., 1989). Each participant depending on the site was called to answer the elicitation and a follow-up question concerning their willingness to pay for participatory climate information services which were to date unknown:

Study site

Imagine that a private company is willing to provide you similar climate service that you are receiving currently through the WATERAPPS project. To cover the costs, the company is charging –First Bid------ Taka as a subscription fee per month from each farmer. Will you accept this offer? If the company is charging …… follow-up-bid …. (if the answer is NO to the first bid, select the lower bid and if the answer is YES to the first bid, select higher bid) will you accept this subscription fee?

Control site

Imagine that a private company is willing to provide you detailed weather forecasts (5-14 days in advance). This information can be used for changing planting dates, deciding crop acreage, deciding crop varieties, change of land preparation dates, changing fertilizer and pesticide application dates, hiring of labour, etc. To cover the costs, the company is charging –First bid------ Taka as a subscription fee per month from each farmer. Will you accept this offer? If the company is charging …follow-up-bid… …. (if the answer is NO to first bid, select the lower bid and if the answer is YES to the first bid, select higher bid) ….. will you accept this subscription fee?

Based on the two aforementioned questions, the following four possible outcomes were derived:

1. WTP (YY): Accepting both the start-up and the follow-up bid
2. WTP (YN): Accepting the start-up bid and rejecting the follow-up bid
3. WTP (NY): Rejecting the start-up bid and accepting the follow-up bid
4. WTP (NN): Rejecting both the start-up and the follow-up bid

A double bounded Logit model was employed to analyze the data that were obtained from the farmers following the completion of the experiment. The response probabilities obtained for the double bounded-Logit model (following Hanemann et al., 1991; Arshad et al., 2016), are:

$$P_i^{YY} = 1 / (1 + e^{-(\alpha + \beta \, High\ BID)}) \quad (1)$$

$$P_i^{NN} = 1\text{-}1/ (1 + e^{-(\alpha + \beta \, Low\ BID)}) \quad (2)$$

$$P_i^{YN} = 1/ (1 + e^{-(\alpha + \beta \, High\ BID)}) - 1/ (1 + e^{-(\alpha + \beta \, Initial\ BID)}) \quad (3)$$

$$P_i^{NN} = 1/\left(1 + e^{-(\alpha + \beta\, Initial\ BID)}\right) - 1/\left(1 + e^{-(\alpha + \beta\, Low\ BID)}\right) \quad (4)$$

Where:

Initial Bid = Initial bid value

Low Bid = Follow-up lower bid value in case of 'NO' to Initial bid value

High Bid = Follow-up higher bid value in case of 'YES' to Initial bid value

The functional form of the double bounded log-likelihood to estimate the probability of a respondent's willingness to pay for the participatory Climate Information Services is provided in (Eq. 5):

$$L_{DB} = \Sigma\, I_i^{YY} \ln P_i^{YY} + \Sigma\, I_i^{YN} \ln P_i^{YN} + \Sigma\, I_i^{NY} \ln P_i^{NY} + \Sigma\, I_i^{NN} \ln P_i^{NN} \quad (5)$$

Where:

$i = 1, 2, \ldots, 110.$

I_i indicates the response category of individual respondent *'i'*.

Following Hanemann et al. (1991), mean WTP was estimated through Eq. 6:

$$WTP^* = Ln\ (1+e^{\alpha}) / \,|\beta| \quad (6)$$

Where:

$|\beta|$ is the absolute value of the bid coefficient.

The payment vehicle used here in this study was the monthly subscription fee. Several factors were identified and employed in the analysis that could potentially influence the farmers' willingness to pay such as gender, age, education level, family, and farm size. These factors or independent variables that might affect farmers' WTP are further listed in table 5.2. In our analysis, we decided to run two separate models. Model 1 included the bid and the treatment (Treat) variables. For the participants of the FFS that had also received PICSA training Treat variable was assigned the value 1, while for the control group participants this value was 0. In Model 2, besides the Bid and the Treat (which indicates whether the farmers have received PICSA training and they participated in the FFS), several factors were identified and employed in the analysis that could potentially influence the farmers' willingness to pay such as gender, age, education level, family and farm size.

Table 5.2. Variables included in the models.

Variables	Description of variables	Category
Dependent variable:		
Willingness to pay (WTP)	Willingness to pay (WTP) for participatory CIS	4 possible outcomes: ('YES-YES', 'YES-NO', 'NO-YES', 'NO-NO')
Independent variables:		
Treat	Indicates whether the participants/farmers were part of FFS and have received PICSA training	1 = study site; 0 = control site
Bid	Amount of money farmers are willing to pay	Ranges from BDT 10 (minimum bid) to 200 (maximum bid)
Gender	Participant gender	1 = male; 2 = female
Age	Age of household head	1 = 20-29; 2 = 30-39; 3 = 40-49; 4 = 50-59; 5 = 60 and above
Education	Education of household head	1 = Primary; 2 = Secondary; 3 = Graduate; 4 = Tertiary; 5 = No formal education
Fsize		Number of household members
Farmsz		Total area of the farm

5.3 Results

5.3.1 Characteristics of the respondents

Table 5.3 summarizes the socio-demographic characteristics of farmers. The sample size that participated in the WTP experiment was 59 people for the study site group and 52 people from the control site group (111 participants) from whom we collected 110 valid answers. A good ratio of male-female farmers participated in the study. The dominant age group category is 40-49 years (35.6%) for the control site and 20-29 (42.4%) for the control site. Moreover, the study found that the majority of the respondents in the study site have received primary (40.7%) or secondary (49.2%) education, while the majority of the farmers in the control site have received secondary (34.6%) or graduate (40.4%) education. Furthermore, the respondents were asked to indicate the years of farming experience. The dominant categories for the study site group were 11-20 years (27.1%) and 31-40 years (25.4%), while in the control site group 53.9% of the farmers stated that they have 0-10 years of experience. The mean family size is 4.1 and 3.7 people for the study and control sites, respectively, while the farm size is 3.0 and 3.2 acres for the study and control site, respectively.

Table 5.3. Characteristics of the respondents.

Demographics	**Control site (n= 59, results in %)**	**Control site (n= 52, results in %)**
Gender		
male	74.6	57.7

female	25.4	42.3
Age		
20-29	5.1	42.4
30-39	18.6	32.6
40-49	35.6	15.4
50-59	13.6	3.8
60 and above	27.1	5.8
Education		
Primary	40.7	5.8
Secondary	49.2	34.6
Graduate	3.4	40.4
Tertiary	6.8	5.8
Farming experience (years)		
0-10	16.9	53.9
11-20	27.1	28.9
21-30	13.6	9.6
31-40	25.4	3.8
40 and above	16.9	3.8

5.3.2 Farmers' willingness to pay and influencing factors

To further investigate whether the PICSA training and the Farmers' Field School played any significant role in the farmers' WTP, figure 5.5 depict the outcomes of the WTP for participatory CIS (in % following the cases responses) for the study site (FFS) and the control group site, respectively. According to the participants' answers, YES-YES cases (YES to first and follow-up bid) were 50.9%, YES-NO cases were 30.0%, NO-YES cases were 1.8% and NO-NO cases were 17.3%. The results of both tables reveal that 82.7% of the respondents are willing to pay to receive climate information to manage their agriculture activities and only 17.3% are under no circumstances willing to pay for climate information services.

The outcomes of the WTP per examined site that are depicted in figure 5.5 indicated that the share of the farmers of the study site that had received treatment (PICSA training and FFS) and expressed at least one 'YES' response is more than 90%, while this percentage for the control group is slightly above 75%. The results reveal that exposure to climate services in the study site group indeed induced a higher WTP, in comparison to the control site group. In any case, the majority of the participants from both groups are willing to pay for Climate Information Services, regardless of whether they have participated in their co-development, showing its commercial potential.

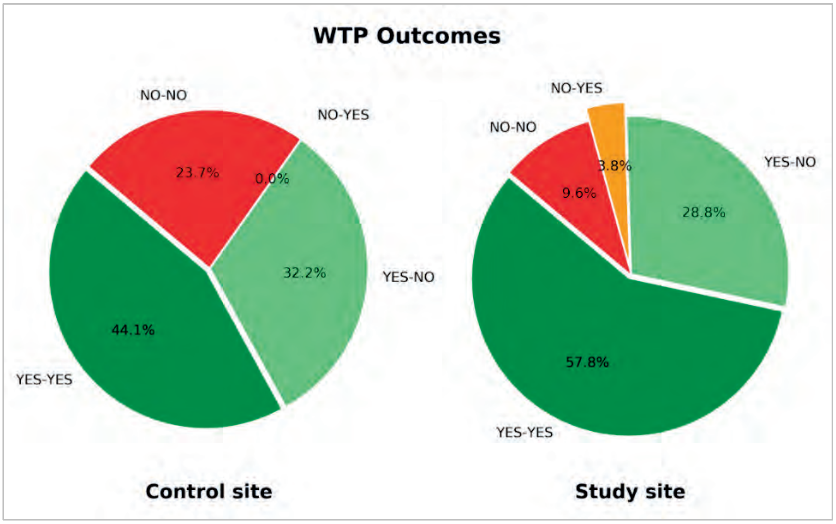

Figure 5.5. Outcomes of the willingness to pay per examined site.

Following, the results of the DB-logit for model 1 included only the Bid and Treat variables, and Model 2 that included all independent variables that are mentioned in table 5.2, are shown in tables 5.4 and 5.5.

Table 5.4. DB-logit results for WTP (Model 1 - including only treatment and bid variables).

Variable	**Coeff.**	**Std. error**	**t-stat**
CONSTANT	1.8499	0.3245	5.701
Bid	-0.0263	0.0036	-7.204
Treat	1.2649	0.4214	3.002
Restricted WTP point estimate in BDT (USD*)	**95.82Tk (1.13$)**		
Krinsky and Robb confidence intervals (95% C.I.)	**81.75Tk (0.96$) - 116.23 (1.37$)**		
**Exchange rate as of March 12, 2021*			

Table 5.5. DB-logit results for WTP (Model 2).

Variable	**Coeff.**	**Std. error**	**t-stat**
CONSTANT	2.33	1.2550	1.86
Bid	-0.002689	0.0038	-7.123
Treat	0.95065	0.5243	1.813
Gender	-0.0736	0.4681	-0.1572
Age	-0.01868	0.0179	-1.044
Education	0.08945	0.3505	0.2553

Fsize	0.06281	0.1475	0.4258
Farmsz	0.01926	0.4068	0.04735
Restricted WTP point estimate in BDT (USD)	**95.35Tk (1.12$)**		
Krinsky and Robb confidence intervals (95% C.I.)	**80.91Tk (0.95$) - 116.23 (1.36$)**		

The coefficient value (β values) indicates the importance of some predictors of the probability to pay for participatory climate information services. As such, it determines which actions should be prioritized for promoting WTP for environmental goods (Al-Amin et al. 2020). According to the results in tables 4 and 5, both models present negligible differences. The coefficient of Treat (Model 1: $\beta = 1.2649$, Model 2: $\beta = 0.95$) is positive for both models, which indicates that this factor positively influences farmers' WTP for participatory climate information services. For example, if the Treat variable increases by 1 unit (if farmers receive more training on climate information services), WTP for participatory CIS increases by 1.26 and 0.95 for model 1 and model 2, respectively. Furthermore, the coefficients of Education ($\beta = 0.089$), family size ($\beta = 0.062$) and farm size ($\beta = 0.019$) are also positive.

Thus, this implies that WTP and the aforementioned independent variables are positively correlated. On the other hand, the Bid variable showed a negative correlation for both models. According to the BD-logit results, the coefficient of Bid is negative for both models (Model 1: $\beta = -0.0263$, Model 2: $\beta = -0.0026$) as was expected a priori and is in both cases the most dominant driving factor that influences the farmers' willingness to pay for these services. For example, if the value of the offered participatory CIS increases by 1 unit, WTP will decrease by 0.0263 and 0.0026 for models 1 and 2, respectively. Other variables like age, education, farm size, or gender had no significant relation with the probability of their willingness to pay. It is encouraging that female farmer are equally willing to pay compared to male counterparts. On the other hand, the treatment i.e. exposure to climate service is the variable that had the strongest positive influence in terms of explanatory variables that affected the farmers' probability of willingness to pay.

Overall, the mean willingness to pay for weather and climate information services when using only Treat as an explanatory variable is 95.82Tk (1.13$) per month or 1,149.84Tk (13.56$) per year. The farmers are willing to invest a minimum of 981Tk (11.57$) and a maximum of 1,394.76Tk (16.45$) per year. According to the results of model 2 that included several explanatory variables besides treatment such as gender, age, education, farm, and family size, farmers are willing to invest 95.35Tk (1.12$) per month or 1,144.20Tk (13.49$) per year. The annual minimum amount is 970.92Tk (11.45$), while the maximum is 1,387.20Tk (16.36$).

5.4 Discussion

5.4.1 Factors that affect farmers' willingness to pay

Following the outcomes of the DB-logit model results, both models are presented with similar results regarding the mean willingness to pay. In both cases, the bid variable or else the money that a farmer is requested to pay for the service within the hypothetical market was the most important factor that affected the farmers' WTP for participatory CIS. The negative sign indicates that the higher the subscription fee is, the lesser are the chances of a positive response. According to Fonta et al. (2018), this might be due to the difference that exists between the proposed bid amount and the individual's true reservation price for this scheme and has a significant policy implication for governments. Nevertheless, this finding is important and coherent with the outcomes of the current study since the amount of the proposed bid as resulted from both applied models is the key determinant for farmers to invest in CIS. It also indicates that farmers were seriously considering payment and not simply responding 'YES' to the questions. To this direction, the governmental institutions in Bangladesh could play a major contributing role on that by investing in Weather and Climate Information Services to make them more affordable for farmers or by providing subsidies for CIS for the agricultural sector if the lower willingness to pay for CIS becoming a hurdle in their widespread use, especially in the initial years of establishment of such services. It is also shown that once farmers get exposed to the service, their willingness to pay increases significantly. A suggestion would be for the Bangladeshi government or the corresponding governmental institutions such as the DAE either to provide these services themselves or to subsidize at least a year of service to promote private entities offering such services.

The relationship between the probability of willingness to pay and the provisioned service value (Bid) that was found in the current study is also consistent with the findings of previous studies (Arshad et al., 2016, Akter et al., 2009, Fuks and Chatterjee, 2008). Besides bid, age also showed a negative correlation regarding the farmers' willingness to invest in CIS which comes following the results of Ouédraogo et al. (2018) in Burkina Faso as farmers who were willing to pay for CIS tended to be younger people. This could be attributed to the fact that the younger people do have more frequent access to information technology through their smartphones and they are more capable of searching and finding weather and climate information from multiple sources without having to pay for that. Education of farmers is another aspect that positively influences farmers' WTP for participatory CIS as it resulted from the current study. The WTP outcomes were similar with studies conducted among smallholder farmers in Malaysia where the results of Ahmed et al. (2015), Banna et al. (2016), Masud et al. (2017), and Al-Amin et al. (2020) all indicate that education greatly influences farmers' WTP and farmers with high level of education and climate change concern are more willing to pay for climate adaptation programs.

Education could help raise awareness among farmers concerning weather and climate extremes (Moore and Lobell, 2014), and in that line, the treat variable showed a significant positive correlation which indicates that farmers that have received advanced training on Climate Information Services are more willing to pay for those. The main reason is that the farmers through engagement and capacity building are becoming more knowledgeable and thus more aware of the increased hydroclimatic variability and what this implies for their agricultural livelihoods. Through training and information that they received from the participatory CIS, local farmers are probably able to better understand and interpret the prevailing weather phenomena and thus can make more sophisticated decisions concerning agriculture that leads to socio-economic benefits besides increased adaptive capacity.

According to the results of Model 2, WTP is dependent on many factors that play less or more important roles and, in this line, additional physical, environmental, and socio-economic parameters could be considered while assessing someone's WTP for CIS. For example, Meza et al. (2008) argued that the value of seasonal forecasts for agriculture depends on many factors including farmers' risk attitudes, insurance, policy environment, and scale of adoption. Moreover, Zongo et al. (2016) assessed the farmers' perception and willingness to pay for climate information in Burkina Faso and showed that besides education of farmers that positively influences the demand for CIS, awareness on climate information also had a significant positive effect on farmers' WTP which confirms the outcomes of the current study. Uddin et al. (2016) researched the farmers' WTP for agricultural extension services in the coastal region of Bangladesh and found out that quality is influencing payment decisions and the type of services that farmers are willing to pay. Besides services quality, a barrier that is an inhibitory factor and was identified by Kumar et al. (2020a) for the similar study site case in Khulna, Bangladesh is the lack of ICT-knowledge of the local farmers, which however has been significantly increased since the beginning of the WATERAPPS engagement. Moreover, since the human capacity for development is there, as it is technology, the only thing that is lacking according to Islam and Grönlund (2011) is useful services adapted to the rural usage patterns and social context and the WATERAPPS project approach of co-developing tailor-made climate information services with and for the local farmers for sustainable agriculture offers a possible model for social entrepreneurship.

5.4.2 Capacity building and participatory co-development influence on farmers' WTP

The main characteristic of the offered Climate Information Services was the participatory process that was followed during the study for the participants of the study site. According to multiple scholars, participatory co-production of CIS is becoming increasingly common over the last few years (Gbangou et al., 2020b, Goodess et al., 2019, Simelton et al., 2019, Willyard et al., 2018, Taylor et al., 2017, Hewitt et al., 2017, Beier et al., 2017). Moreover, successful Climate Information Services are developed through a bottom-up approach with strong involvement of farmers and interested stakeholders in the supply chain in a co-production model to better understand the priorities and practical requirements the services must have (Georgeson et al., 2017). The training that was offered by PICSA to the study site farmers and subsequently their involvement in the co-development of CIS aimed at building and further developing their capacity towards weather and climate-related phenomena concerning agriculture. The capacity of local agricultural extension officers (DAE) is also improved on similar FFS approaches (Kumar et al., 2020b, Kabir and Rainis, 2015, Bijlmakers and Islam, 2007) and following the finalization of the WATERAPPS FFS, they also expressed the will for services upscaling so to reach, enable and build the capacity of farmers in Bangladesh to take informed decisions to agricultural livelihoods. In general, formal institutions via their communities play an important role in building capacity for adaptive agriculture (Islam and Nursey-Bray, 2017), so in this case, the extension officers could significantly contribute to service upscaling and capacity development. The latter is of great importance and a critical component of climate information services as it allows users to provide input and be involved in the collaborative process of co-developing tailor-made Climate Information Services.

5.4.3 Way forward

Weather and Climate Information Services have the potential to support Bangladesh's sustainable and resilient agricultural development by providing tailor-made information that could enhance agricultural production mitigate farm losses, increase economic incomes and improve food security. The Government of Bangladesh, along with the Bangladesh Meteorological Department (BMD) and the Agricultural Extension Office (DAE) as well as a range of stakeholders and private weather forecast providers and farmers need to follow a coordinated and cooperative approach to produce and deliver meaningful and effective CIS to end-users.

The participation of the farmers that are also the end-users of the product is of great importance. Farmers are engaged in the process to derive a system that is tailor-made to their needs, they invest personal time and resources in the procedure and they gradually consider the output product as 'their' product, make full use of it, and tend to advertise it to peer farmers, that they haven't taken part in the FFS. Additionally, they continue investing and relying on the service despite minor economic losses that might occur from time to time due to forecast uncertainty and are willing to pay for the service which indicates the commercial potential of the service. This is yet another reason why governmental organizations should invest in similar services.

In this line, the way forward should specifically focus on building and increasing the peri-urban farmers' capacity towards weather and climate-related phenomena by providing training, initiating weather schools, and organizing workshops on concepts regarding water, weather, and climate-related phenomena about land-use activities. Adaptive decision-making should be seen as a participatory process that includes active engagement and empowerment of farmers, key stakeholders, researchers, and governmental and private organizations with the knowledge and capacity to uptake the outputs of participatory weather and climate information services. To this aim, especially the Agricultural Extension Office (DAE) of Bangladesh is called to play a major role as they have the network and resources to support and upscale the services and contribute to sustainable agriculture.

5.5 Conclusions

The current study examined the farmers' willingness to pay for participatory climate information services in the peri-urban city of Khulna, Bangladesh in the Lower Ganges Delta, a rich agro-ecological zone that is highly prone to increase hydroclimatic variability and is vulnerable to climate change. To conduct the research, two study sites were selected: an experimental study site where the farmers are co-developing Climate Information Services within the scope of the WATERAPPS project and a control group site where farmers received no prior training on CIS. Several explanatory variables that affect the farmers' willingness to pay for CIS were taken into account such as the provisioned cost of the CIS, whether or not farmers are receiving Climate Information Services, gender, age, education as well as family and farm size.

The outcomes of the study indicated that on average more than 4 out of 5 farmers are willing to pay to receive tailor-made weather information that could assist them to deal with the hydroclimatic variability by making more sophisticated and tactical decisions for everyday agricultural activities. The percentage was higher (90%) for the study site participants that had received prior training on weather and climate information services and were participating in the Farmers' Field School and the co-development of agricultural advisory information based on the provided forecast. By the completion of the FFS the local farmers following the socio-economic benefits that were generated, expressed the need for the services to continue and they established a Weather Club[3] to ensure the continuation of the services. Agricultural extension officers were also engaged with the FFS and showed great interest in participating in the study and assisting towards services upscale. The control group's results regarding the farmers' willingness to pay were also high (75%) which indicates that also these farmers that haven't received prior training and capacity building on CIS are willing to invest in these services as they no longer rely on traditional practices.

The study showed that farmers are willing to invest 95.35Tk (1.12$) per month or 1,144.20Tk (13.49$) per year. The annual minimum amount is 970.92Tk (11.45$), while the maximum is 1,387.20Tk (16.36$). Given the fact that the number of farmers in Bangladesh exceeds 100 million, it shows a huge market size for the service if a similar willingness to pay for such services exists all over the country. The overall high willingness of farmers to pay for tailor-made climate information services regardless of whether they have received prior training and capacity building on weather and climate-related phenomena concerning agriculture indicates how vital these services are for the local farmers. Hence, the Bangladeshi government, through its governmental organizations such as the Agricultural Extension Office should consider investing in these services to make them more affordable farmers. Alternatively, these services by private players or social entrepreneurs could be subsidized for a period, which could assist towards creating a market for Climate Services and also to promote private entities investing in tailor-made climate information services. These services could de-risk farming activities and enhance the climate resilience of Bangladesh's agriculture, unlocking its hidden potential.

[3] http://www.waterapps.net/en-us/bangladesh-updates/weather-club-a-new-horizon-of-smallholder-farmers-in-the-ganges-delta/

Chapter 6

Discussion, Conclusion and Outlook

Chapter 6

Discussion, Conclusion and Outlook

6.1 Introduction

This dissertation is conducted in the disaster-prone southwest Bangladesh to improve climate information services (CIS) for smallholder farmers. The agricultural system is confronted with these extreme events that hamper food production and the smallholder communities' livelihood security (Huq et al., 2015, Alam et al., 2013, Hussain, 2017, Brammer, 2016, Krupnik et al., 2017). While CIS could potentially help farmers agricultural decision-making (Shikuku et al., 2017), previous studies showed that there is a lack of understanding, communication, and accuracy of CIS (Alam et al., 2013, Paul and Routray, 2013, Fakhruddin et al., 2015, Rahman et al., 2013). There are urgent calls to improve CIS, particularly for smallholders who are the most vulnerable to climate risks (Huysen et al., 2018, Roy and Alam, 2020, Kundu et al., 2020). Despite some on-going governmental CIS initiatives, knowledge gaps exist regarding: (1) current practices, accessibility, and the role of information, (2) information needs of farmers, and (3) co-production of climate information services through users engagement, capacity building, and co-design of a users' platform using ICT tools such as a smartphone app. In this dissertation, I focused on these knowledge gaps by answering the four research questions as following:

- *RQ-1. What are existing knowledge, local practices, and accessibility to hydroclimatic information of the peri-urban farming communities in the Lower Bengal Delta (Chapter 2)*
- *RQ-2. What kind of hydroclimatic information is needed by smallholder farmers communities for sustainable agricultural practices in the study area (Chapter 3)*
- *RQ-3. What types of information platforms are effective and have the potential for co-producing climatic information services with farmers in the study area? (Chapter 4)*
- *RQ-4: Are farmers willing to pay for participatory climate information services in the Lower Bengal Delta? (Chapter 5)*

I have addressed these four research questions in four scientific articles in Chapters 2-5. The main findings of these scientific articles are presented and discussed in Section 6.1 below. In the subsequent sections, I conferred the synthesis of this dissertation (Section 6.2), methodological strengths and limitations (Sections 6.3), scientific contribution (Section 6.4), social contribution (Section 6.5), and future research outlook (Section 6.6). I conducted a step-wise research investigation to answer the four connected research questions formulated for this dissertation. A graphic representation of the four research questions and key findings is given in Figure 6.1.

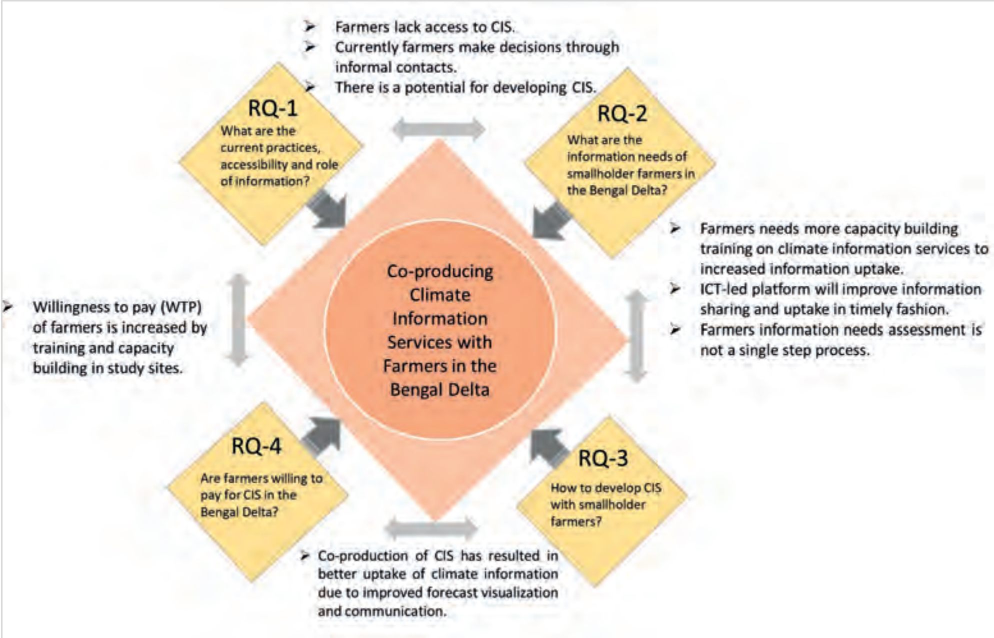

Figure 6.1. Co-producing climate information services with smallholder farmers in southwest Bangladesh. The figure presents the key findings of each research question with four designated research steps. A step-wise research investigation was conducted to answer four research questions following a transdisciplinary research approach and participatory tools. Between the boxes, I have presented the key conclusions next to the research questions.

6.1.1 Main findings of the research questions

- *RQ-1. What are existing knowledge, local practices, and accessibility to hydroclimatic information of the peri-urban farming communities in the Lower Bengal Delta (Chapter 2)*

To answer the first research question, I developed a research and data collection framework combining desk research, reconnaissance field visits, focus group discussion (FGD), farmers' interviews (n=200), and experts' interviews (n=20) using a semi-structured questionnaire and checklists. I conducted the literature review during August – September 2017, and then I started field visits and primary consultation with agricultural extension experts to identify and setup of the field study sites. Rupsa and Batiaghata were purposefully selected for this study, as these are agriculturally dominated peri-urban areas in Khulna districts, Bangladesh. Smallholders of Rupsa and Batiaghata were highly interested in cooperating in field study and accessing location-specific climate information services for crop advisory services to smallholders at the village level.

Findings show that the Department of Agricultural Extension (DAE) lacks access to precise climate information services to support farmers' tactical and strategic decision-making. DAE shares emergency weather warnings using traditional communication channels. Therefore, forecasts often come late or with a short-lead time (1-3 days or less). I observed that SAAOs are responsible for providing extension services to a large number of farmers using personal and group contacts that are not an efficient way of CIS, and many farmers remain unserved. Farmers remain dissatisfied and often claim that DAE fails to understand farmers' information needs and advisory services in a timely and actionable fashion. I conclude that there is a need to have a timely communication of climate information to a large number of farmers. ICT platforms can be used to communicate CIS in a timely fashion. Also, farmers have a high interest in receiving CIS through mobile phones. The majority of farmers already have access to mobile phones. However, most farmers lack the knowledge to use ICT platforms, indicating a need for capacity building on using ICT tools. I conclude that ICT-led services are still very limited in use, therefore farmers attached a little value, indicating a need for capacity training on the ICT platform and service co-development with the local farmers and extension officers.

In this dissertation, I finally identified two new agricultural decision-making determinants: individual considerations and input support from governmental and non-governmental agencies. Also, I sketched 14 major climate-sensitive farming decisions with farmers (Chapter 2). Understanding these decisions is essential for designing information services. For example, a short-term forecast is useful to take fertilizer and pesticide application decisions. Whereas to take cultivation and harvest decisions farmers require extended range forecasts (1-2-week, 1-month). The majority of smallholders currently are involved in integrated agriculture-aquaculture and non-rice cropping practices to adjust to hydroclimatic variabilities. The current adaptation practices involve additional costs and risky behavior regarding cropping plan decision-making. A better CIS can reduce production costs and the risk-behavior of smallholders. Therefore, I conclude that there is a potential for developing climate information services in Bengal Delta addressing farmers' needs and capacity building of farmers, local extension officers, and input dealers. I recommended that a bottom-up co-production approach should be followed for tailored climate information services to ensure usability and usefulness to farmers, and effectiveness of the end product.

- ***RQ-2. What kind of hydroclimatic information is needed by smallholder farmers communities for sustainable agricultural practices in the study area (Chapter 3)***

This research question aims to address the hydroclimatic information needs of smallholders. To fulfill this, I developed and applied a five-step farmers' engagement process - user platform, user engagement, baseline assessment, capacity building, end-line assessment. The engagement process helped to understand the weather and water-related information needs of smallholders. This study was conducted at Sanchibunia, Raingamari, Jharbhanga villages in the Batiaghata sub-district of Khulna. In this study, I compared baseline, and end-line information needs assessment combining field visits, participatory meetings, and personal interviews with farmers (n=60).

I found that during the baseline needs assessment, farmers faced difficulty expressing their specific information needs. Also, they expressed a lack of understanding about forecast availability, accessibility, and usage for informed agricultural decision-making. The majority of farmers stated that climate information is about rainfall and emergency weather warning, occasionally accessed by farmers on television and radio. Farmers had no idea that climate parameters such as sunshine, temperature (max. and min.), wind speed, and cloud coverage could be provided sufficiently in advance (7 days or more). The majority of farmers also reported that weather is a 'God phenomenon.'

However, after capacity building and frequent interaction, experimental farmers noticed a change in their information needs, forecast lead-time, and parameters of interest. After training, farmers also gained a better understanding and they developed trust in forecasts and an understanding of their use in agricultural decision-making. Besides climatic information, farmers expressed water-related information needs – soil and water salinity – for precise agricultural decisions. I found that 1-2 weeks lead-time information was applied by all smallholders, while a few farmers used seasonal forecasts (3-6 months lead-time). This indicates smallholders have a higher preference for forecasts at a weekly and biweekly time-scale than the seasonal time scales (3-6 months). Indeed, all farmers perceived the inter-seasonal forecast's usefulness before starting a crop season, preferably one 1-month ahead.

Finally, the study finding shows that farmers preferred mobile apps for climate information services followed by capacity building and frequent interactions. They also revealed preference about the format of the forecasts: photograph/diagram and audio-video. The FFS platform provided an excellent opportunity for co-production where farmers could develop their awareness and discuss their specific information needs, accessibility, relevance, and usage in a participatory process. I conclude that information needs assessment is not a single-step research process for co-producing climate services. Capacity building and iterative interaction are key to assess information needs more explicitly for co-developing climate services for smallholders.

- ***RQ-3. What types of information platforms are effective and have the potential for co-producing climatic information services with farmers in the study area? (Chapter 4)***

In this study, I aimed to investigate whether the uptake of climate information services can be improved through co-production of how the forecast is visualized and how it is communicated. To achieve this objective, I applied the farmer field school (FFS) approach for communicating visual diagrams of 7-day, 14-day, and seasonal (3-month) forecasts during face-to-face meetings using printed paper, and a smartphone app. A total of 58 experimental farmers were involved in two field schools including both male and female participants in Batiaghata from Mid-June to Mid-November 2020. I developed a new framework for the co-production of CIS through forecast visualization and communication to influence farmers' decision-making. I collected primary data through primary meetings, weekly interaction at FFS, and personal interviews using semi-structured checklists and questionnaires.

The results show that smallholders gained better understanding and interpretation skills of visual forecast diagrams after iterative interactions and training. The majority of farmers followed the 7-day and 14-day forecasts, while very few (6%) farmers followed the seasonal forecast. I conclude that during the crop seasons, higher usefulness and potential are attached to the 7-day and 14-day time-scale forecasts to smallholders in the Bengal Delta. Also, all farmers preferred seasonal information preferably 1 month in advance of the crop seasons. I found that understand and presenting forecast uncertainty is one of the critical aspects which resulted in increased use of the forecasts by smallholders. Most farmers indicated that forecast uptake was facilitated through a better understanding of the uncertainty of probabilistic forecasts.

Finally, farmers reported an increased uptake of the forecast information due to improved capacity and improved communication attributes (Chapter 4). Farmers highly valued feedback collection in weekly meetings as it offered a comparison with farmers' local observation, and thus strengthened their trust in the service co-production. I observed that farmers frequently accessed forecasts from field schools which reduced their dependence on traditional platforms. I conclude that co-production effort at field schools through forecast visualization and communication resulted in broader sharing, dissemination, and uptake of the scientific forecasts. I also noticed a behavioral change of smallholders due to training, frequent interactions, and the participatory co-production process. The majority of farmers reported their behavioral changes in terms of increased awareness level and frequently access forecasts for both agricultural and non-agricultural decision-making.

- ***RQ-4: Are farmers willing to pay for participatory climate information services in the Lower Bengal Delta? (Chapter 5)***

This part of the study aimed to address the willingness to pay (WTP) of smallholders for CIS that are being co-produced in Khulna, Bangladesh. A double-bounded dichotomous contingent valuation method was employed to estimate the farmers' willingness to pay (WTP) for participatory climate information services. I analyzed the WTP of the experimental farmers, and I compared it with a control farmers group in the same geographic area at Mathavanga village. I conducted training and participatory interactions on climate information services for the experimental farmers' groups, where the control farmers group confirmed that they had no prior training and participatory interactions on climate information.

The results show that the majority of farmers (80%) are willing to pay for tailored climate services. The provisioned WTP value for CIS is the main driving factor, followed by whether the farmers have received training and capacity building on weather and climate-related phenomena. However, at the control site, 75% of farmers indicated that they are willing to invest in location-specific tailored weather and climate information services for agricultural practices and decision-making. I conclude that with and without training the majority of farmers revealed a high interest in climate services. The local agricultural extension officers also showed an active interest in climate services. They also indicated an upscaling need for more location-specific mechanisms at sub-district levels so that DAE field officers could assist local farmers through appropriate advisory services. Finally, I concluded that tailored CIS has a business potential in the Lower Bengal Delta. Governmental organizations such as BMD, BWDB, DAE, and AIS could proactively invest in co-developing CIS involving their regional and local offices and making them locally affordable and accessible to farmers. Besides, financial organizations such as banks and micro-finance agencies could also contribute by co-designing climate services insurance packages for farmers. CIS insurance packages are yet to be developed in the Bangladeshi context. Finally, I concluded that tailored CIS has a business potential for agricultural development and climate-resilient food production system in the Bengal Delta.

6.2 Synthesis - Connecting the Main Findings

In this section, I draw links with the key research findings and discussed the broader perspective of the research findings in the light of existing literature and global perspectives.

6.2.1 Co-producing climate information service with smallholder farmers

There is an increasing demand for co-producing climate information services (CIS) for smallholders in developing countries (Gbangou et al., 2020a, Kolstad et al., 2019, Hewitt et al., 2020, Turnhout et al., 2020, Vincent et al., 2020a). As in other developing countries, there is a need for short, medium, and long-range CIS for Bangladeshi smallholders (Islam et al., 2013, DAE, 2018b). As a lack of CIS could aggravate the risk for poverty and hunger of smallholders (Funk et al., 2020), I conclude that CIS co-production is urgently needed for smallholders for agricultural decision-making (see Chapter 2). Several studies have parallel research findings in developing countries (Sultan et al., 2020, Hampson et al., 2015, Kundu et al., 2020, Rasmussen et al., 2014). This is also reflected by repeated global CIS call for smallholders especially in Asia and Africa (WMO, 2016, Tall et al., 2018, Tall et al., 2014). Globally smallholders account for 80-90% of farm-households (Rapsomanikis, 2015). They contribute a major share of global food production, however, they are still heavily dependent on traditional forecasts and seasonal weather conditions. A participatory co-production therefore can generate credible, salient, and legitimate CIS to help smallholders globally (Buontempo et al., 2014, Clifford et al., 2020, Brooks, 2013, Hewitt et al., 2020, Blench, 1999).

The farmer field school (FFS) platform can be applied for service co-production and deliver CIS effectively to smallholders (Chapter 4). This could be replenished existing top-down climate services. Scholars report that ICT-led platforms can support the co-production process and smallholders' decision-making (Kashem et al., 2010, Inwood and Dale, 2019). However, ICT tools support is needed for smallholders to overcome present limited access to ICT tools, and initial inspiration, training, and knowledge co-production (Sarku et al., 2020b, Gbangou et al., 2020a). With regards to the CIS call in Bangladesh (Kundu et al., 2020, Roy and Alam, 2020, Kumar et al., 2020a) and other developing countries (WMO, 2016, Tall et al., 2018, Tall et al., 2014), I demonstrated how to co-develop an effective co-production process at FFS engaging farmers, extension officers and local actors (Chapter 4). This co-production approach could be applied in another context. Indeed, there is a sustainability challenge of co-produced CIS reported by scholars (Vincent et al., 2020b, Daly and Dessai, 2018). I conclude that with capacity-building training and participatory engagement, a sustainable service collaboration will be continued once it is co-produced at the farmer field school platform (FFS).

In this dissertation, the co-production experiment resulted in a better-understanding of forecast uncertainty through sharing forecasts, interactions, and capacity-building of extension officers and farmers with an iterative co-production effort (Bremer and Meisch, 2017, Gbangou et al., 2020a, Prokopy et al., 2017). I conclude that the participatory co-production process has increased information uptake using smartphones and peer-to-peer communication that can be replicated in other study settings. A similar research finding was also reported by Gbangou et al. (2020a) and Sarku et al. (2020b) in Africa. Smallholders in developing countries are highly connected. This provides an excellent opportunity through the social nature of quickly information sharing and informed decision-making among smallholders in a connected society. I conclude that in a connected society like Bangladesh, information dissemination and uptake are relatively high with relatively limited access to ICT-led platforms once it is co-produced at FFS (Kumar et al., 2021). Therefore, this research shows that a few smartphones in a village could lead to wider information sharing by peer-to-peer communication as smallholders live in a connected society in the developing countries.

In summary, a participatory co-production significantly increased farmers interest and trust in using scientific forecasts information, and as a result have reduced crop production costs (Tall et al., 2018), and increased crop yields through improved climate-sensitive decision-making (Nyamekye et al., 2020, Bacci et al., 2020, Cliffe et al., 2016). The use of climate information has also increased socio-economic and environmental outcomes (Chapter 4). Finally, I conclude that a participatory co-production at FFS will increase uptake through improving local collaboration, capacity building, trust, and ensuring communication between producers and users elsewhere (Vincent et al., 2020c, Amwata et al., 2018, Vaughan et al., 2019b, Kruk et al., 2017, Vedeld et al., 2019).

6.2.2 Bridging the gap between scientists and end-users farmers

The gap between scientists and end-users is historically rooted in socio-economic, political, and legal-institutional frameworks (Hewitt et al., 2020, Wong-Parodi and Babcock, 2020). Most climate information services are still one-way and supply-driven and have very little or no uptake of and preference from end-users (Carr and Onzere, 2018, Kumar et al., 2020b, Pennesi, 2011, Vedeld et al., 2019). To overcome this gap, I initiated multi-stakeholder workshops suggests by scholars for improving climate services for smallholders (Cliffe et al., 2016, Roncoli et al., 2009, Hansen et al., 2011). I conclude that a multi-stakeholder workshop is crucial to unpack the decision-making processes of smallholder farmers (Vincent et al., 2018) as well as to reduce the gap between service providers and end-users.

However, a major challenge is to develop the multi-stakeholder platform especially with relevant governmental agencies who have no mandate and expertise to support smallholders at the local level. For example, DAE is highly connected with smallholder farmers at the local level. Therefore, DAE field officers were interested and willingly participated in the CIS co-production process. However, BMD, BWDB, and AIS officers are hardly connected with farmers. Therefore, they were less interested to be engaged in a participatory co-production process with limited human resources and without any institutional partnership with higher authority. I conclude that a higher-level institutional partnership is needed for a successful CIS co-production and services sustainability which I did not achieve in this dissertation. A new form of institutional motivation, knowledge infrastructure, and institutional niches are needed to extend service co-production. For example, DAE has extension officers at the local level to support end-user farmers. Thus, likewise DAE, the BMD, BWDB, and AIS could assign extension officers at the local level to coordinate CIS with the agricultural extension and farmers.

To start such an initiative, capacity building of farmers and extension officers is a prerequisite to assess the information needs of farmers. Without capacity building, smallholders often cannot express their information needs (Kumar et al., 2020a). Capacity building is therefore vital for assessing information needs and improving information uptake for climate-sensitive decision-making by smallholders (Sultan et al., 2020, Finucane et al., 2013, Cliffe et al., 2016, Kusunose et al., 2019, Roy and Alam, 2020). Also, without capacity-building efforts, co-produced services will have limited or no significant uptake (Bremer et al., 2019). I observed that smallholders had no idea about the time-scale of forecast information. They occasionally use to uptake information through radio and television for the next day or at best on a 1 to 3-day time-scale during emergency weather warnings such as cyclones and storm surges. With capacity building and repeated interactions and discussion on forecast timescales, farmers expressed their needs for weekly, bi-weekly, seasonal (1/3-month) forecasts. Different time-scales forecast information is therefore needed for tactical and strategic decision-making of farmers. This dissertation also specifies that the information needs of farmers may change over time and capacity building contributes to better understanding and uptake through engagement and capacity development. I conclude that farmers also discover and learn what is available and how it will be useful in their decision-making process over time and decision-making experiences.

The value of forecasts is not valued automatically (Stewart et al., 2004). Effective and timely communication is key to influence decision-making and achieves forecast value (Stewart et al., 2004, Nesheim et al., 2017, Sivakumar, 2006, Moeletsi et al., 2013b). In many cases, farmers are unable to take timely action to effectively reduce hydroclimatic risks, thus limiting uptake of such information services. For example, during the rice harvest period, a 1-3 days advance forecast is not enough to safely harvest paddy from the fields. Also, if there is a big cyclone with an extreme rainfall event. In that case, it causes substantial crop damages and loss of livestock and food production that could lead to food shortage on the smallholders' local and national scales and food insecurity (Zuma-

Netshiukhwi et al., 2016). This dissertation shows that with a 7- and 14-day forecast, farmers significantly can reduce their crop and household damages by emergency preparedness (Kumar et al., 2021). I conclude that 7- to 14-day forecasts could have significant socio-economic, financial, and environmental outcomes (Cliffe et al., 2016) and disaster risk reduction. However, trust-building on scientific forecasts is another essential precondition to reduce the gap between service providers and end-users and to accomplish CIS benefits. I conclude that a co-production will be more trusted to the smallholders as it is built on iterative engagement and feedback between producer and end-users in a participatory knowledge co-creation process (Mach et al., 2020, Kruk et al., 2017, Jagtap et al., 2002, Nyadzi et al., 2019). However, to avoid mistrust, forecast uncertainty must be communicated (Pennesi, 2007).

The choice of communication platform depends on personal, socio-economic, and cultural factors, and can change over time. To date, traditional platforms such as radio and television are highly preferred platforms to smallholders in developing countries (Ahsan et al., 2020, Hampson et al., 2015, Stigter et al., 2014). I observed lack of ICT knowledge, lack of financial capacity, and poor mobile network are also key factors regarding the choice of communication platform (Kumar et al., 2020b). Indeed, smartphone app was highly preferred by smallholders although many of them had no access to a personal smartphone. I found young farmers were highly interested in using a smartphone app and social media after receiving training. The majority of farmers, extension officers, and experts opinioned that a few smartphones in a village community can lead to wider information dissemination and uptake in Bangladesh. Also, the rapid expansion of mobile technology will further enable smallholder farmers to access and use a smartphone for agricultural information and decision-making as was also found in another study (c.f. Fulazzaky and Akil, 2009).

Climate scientists suggest that information should meet three essential quality criteria: salience, credible and legitimate (Buontempo et al., 2014, Kirchhoff, 2013, Moeletsi et al., 2013a) like other developing countries, the national climate services in Bangladesh still do not fulfill salient (time-specificity) and credibility (location-specificity) characteristics to farmers at the local level. Therefore, the majority of farmers still dependent on the tradition for farming decisions. I demonstrated that if farmers have access to scientific forecasts (SF), it has high value to them (Chapter 4). Although in Africa, Nyadzi et al. (2019) and (Gbangou et al., 2020b) found that traditional forecasts have value to smallholders, I found a low value of traditional knowledge-based forecasts among peri-urban farmers in Khulna, Bangladesh. I conclude that SF information is more accepted and reliable with training and capacity building of smallholders. Traditional indicators based forecasts mainly have a very short time-scale. Therefore it is less like to be useful for taking precise tactical and strategic decision-making.

In summary, training and capacity building with ICT-led tools can play a significant role in reducing the producer-users information gap and creating user-friendly digital platforms with better trust and capacity building (Gbangou et al., 2020a, Stienen et al., 2007, Ahsan et al., 2020, Manige et al., 2013). The ICT-led platform also allows producers and users to provide feedback, including service monitoring and re-shaping services based on end-user feedback (Sarku et al., 2020b, Jonoski et al., 2013). Lastly, I conclude that a participatory co-production process, with needs assessment, capacity building, and use of ICT platform is a more insightful co-production, which provides the best learning opportunity for farmers to access and share information quickly among peer farmers, helping them timely delivery of information for agricultural decision-making.

6.3 Study Strengths and Limitations

This dissertation's major strength appeals that a bottom-up co-production process has been addressed to bridge gaps among scientists, intermediaries, and end-users through organizing multi-stakeholder workshops, iterative interactions, and capacity building (Kolstad et al., 2019, Naab et al., 2019). A growing number of empirical studies show that the current co-production process is narrowly framed (Bremer et al., 2019). I demonstrated that a participatory co-production at field school (FFS) augmented the sense of ownership (Gbangou et al., 2020a) and smallholders' affinity towards forecast uptake (Kumar et al., 2021). Also, a multi-stakeholder collaborative process generated a strong relationship and trust between service providers and users, a pre-condition for a successful co-production process (Mubaya et al., 2020, Hansen, 2002, Kruk et al., 2017, Daly and Dessai, 2018). Finally, I conclude that a participatory process motivated farmers and extension officers in organizing communication ‘virtual platform - weather club’, and extended use of smartphones and social media to uptake climate services (see Chapter 4).

Currently, climate information production and dissemination are highly clustered (Ofoegbu and New, 2020), indicating a lack of engagement of different actors in the co-production process (Nyadzi et al., 2018). For scientists, it is often challenging to arrange engagement and collaboration with providers and end-users (Kolstad et al., 2019). In this dissertation, I found it is too difficult to engage governmental actors who are not connected with end-users. The institutional legal issue also limits them from joining the participatory co-development process. Indeed, I observed that a personal network can be useful to influence the engagement process, including quick access to local governmental actors through informal means and field support for engagement and collaboration. I conclude that a personal network can also support a participatory co-production process.

The new generation climate services should comply with quality criteria: salient (relevancy), credibility (quality accuracy), and legitimacy (legal entity) (Buontempo et al., 2014, Kirchhoff et al., 2015, Moeletsi et al., 2013a, Vincent et al., 2020c). These quality criteria are vital to influencing end-users decision-making (Hansen et al., 2011). With advanced science and technological innovation, information quality and CIS will be improved. However, in developing countries, overcoming these CIS quality criteria is still challenged due to poor knowledge infrastructures, lack of local institutional policy, lack of institutional and personal capacity, and a feedback mechanism from the end-users. Some challenges also present within or between organizational domains to initiate co-production. This is required a new form of institutional approach and policy support, and knowledge infrastructure at national and local scales, including training and capacity building of different actors and long-term institutional and financial arrangements.

A new form of CIS governance, therefore, is needed to develop knowledge infrastructure and facilitate the local level's co-production process. I found that this is extremely difficult to develop governmental actors' collaboration (Vincent et al., 2020b) using publicly available open-access CIS. I used meteoblue open-access and accredited web-platform for the co-production process for this dissertation. It was salient and credible to farmers at the local scale. Therefore, during co-production farmers fully rely upon meteoblue forecasts instead of national services in decision-making (Chapter 4). However, local met agency and agricultural extension departments were unwilling to communicate far better quality climate information services that are publicly available via open-access sources such as website and app-based. First of all, there is a legal constraint for the communication of open-access information services with sectoral end-users by the governmental extension department. Therefore, it is one of the most challenging tasks for scientists, service providers, and end-users to develop CIS partnership and governance arrangements for a sustainable co-production process. With science and technological advancement more and more open-access platforms will be developed. Thus, the major question is how to collaborate with such multilateral initiatives when national climate services remain far poor and farmers would not use national climate services anymore. This means that a far better quality climate information may also come other than the national governmental platform. I conclude that overlooking all these important issues must be addressed for the sustainability of co-produced services beyond a project's lifespan.

Secondly, smallholders have a higher willingness to pay for CIS in southwest Bangladesh (Chapter 5) (c.f. Ahsan et al., 2020). I concluded that there is an opportunity for a business case in the Bengal Delta. However, a detailed study is needed to further assess WTP for smallholders. WTP may vary with gender dimensions, socio-economic and environmental factors (Al-Amin et al., 2020, Antwi-Agyei et al., 2020, Tesfaye et al., 2020). It may also vary with geographic location and several reasons such as farm-size, education, income, family size, and vulnerability hotspot (Al-Amin et al., 2020, Antwi-Agyei et al., 2020). It would be relevant to set up a business case experiment for co-design of insurance packages, and this was not investigated in this dissertation. Other regional differences, crop and season specificities were also not studied in this dissertation.

Finally, from a service evaluation point of view, a control site comparison would provide more insight on co-production and its contribution towards the value of uptake and decision-making. In this study, I only supported a group-wise internet facility and two tablets to facilitate the farmers' training programs and interactions. To improve access and use of ICT tools, farmers need more ICT tools and training support (Sarku et al., 2020b, Gbangou et al., 2020a). This dissertation demonstrated that farmers had improved climate information services for agricultural decision-making once they received ICT access and relevant training. Other socio-economic factors may also influence the uptake that was not considered during the CIS evaluation in this dissertation. In conclusion, there is a need to bridge legal institutional gaps to scale-up climate services co-produced through a bottom-up participatory process. A multi-year sustainable collaboration and partnership are needed to build new knowledge infrastructures, capacity building, and need-based co-production CIS.

6.4 Scientific Contribution

To date, significant research effort has been made by scholars working on climate information services (CIS) to help farmers' decision-making. However, past studies were narrowly framed (Bremer et al., 2019) farmers' platform for co-production. I apply the farmers' platform (FFS) as the center of co-production, co-communication, and co-dissemination. The final evaluation result provides empirical evidence of a successful co-production process at FFS. To the best of my knowledge, such a CIS co-creation process (co-production, co-communication, and co-dissemination) with smallholder farmers hardly exists. Also, the transdisciplinary research framework applied for this dissertation contributes to scientific CIS understanding in a smallholder context which can be applied in other study settings.

Farmers' needs assessment is an essential step for CIS co-production (Clifford et al., 2020, Sultan et al., 2020). So far, no study explicitly recognized that needs assessment is not a single-step process. This dissertation reveals that farmers require capacity-building training with information provision to express needs and influence decision-making (see Chapter 3). Farmers' information needs may change over time, and capacity building (Tall et al., 2014, Rengalakshmi et al., 2018, Hampson et al., 2015, Partey et al., 2020). Therefore, the needs assessment has to be conducted through an iterative process for a successful co-producing and to adjust needs-based information needs over time. This understanding will help climate scientists and service providers to address end-users needs more explicitly for CIS co-production.

I developed a conceptual framework of co-production through forecast visualization and modes of communication. To date, none of the co-production studies realized that forecast visualization is an essential attribute in co-production with smallholders. Besides, existing literature rarely focuses on farmers' and local extension officers' capacity building as an integrated part of co-production. I demonstrated that a participatory co-production at FFS has not only improved forecast uptake for tactical and strategic decision-making but also improved emergency preparedness and disaster risk management of farmers. Besides, the co-production process at FFS has led to broader dissemination and usage of forecasts for livestock and aquaculture ponds management and non-agricultural decision-making such as personal travel and planning for socio-cultural events.

A 7- to 14-day weather forecast can significantly reduce smallholders' disaster risks in hydroclimatic disaster-prone areas like Bangladesh through emergency preparedness at households and farm levels. This dissertation placed this noble finding in climate service literature. To date, climate service literature does not have such evidence on disaster management using co-produced and co-created climate information services with smallholders. This pragmatic evidence will inspire scientists and disaster management practitioners to initiate CIS co-production engaging smallholders at FFS. Besides, this research provides evidence that smallholders can reduce 25-50% fertilizer and pesticide input costs if the information is co-produced. This outcome can be achieved in any other hydrometeorological context where smallholders face difficulties to take informed decision-making. The seasonal forecast has potential in strategic decisions, I found that a 1-month lead-time forecast is more appropriate for smallholders in the Bengal Delta than the seasonal forecast with a 3-month or more lead-time (Nyadzi et al., 2019, Nyamekye et al., 2020). This scientific understanding will help scientists, service providers, and policymakers co-producing CIS for farmers. I explore smallholders' willingness to pay (WTP) for market-based tailored climate information services. I find that if farmers receive training on CIS during a participatory co-production process they will have higher WTP than the control farmer group who did not receive training. This primary research finding is pivotal for a market-based CIS co-development.

In summary, this dissertation contributes to the scientific understanding of CIS co-production using the farmer field school approach (FFS). Farmers' needs assessment has to be conducted with iteration and capacity-building effort. A participatory CIS framework that includes forecast visualization and communication will increase forecast uptake by smallholders. A co-production process with 7-14 days forecasts can help smallholders' decision-making and disaster risk reduction. Finally, smallholders will express higher WTP if they receive training and complementary services in a participatory co-production. The *'Farmers Weather Club'* is a scientific innovation of the Waterapps co-production process with high acceptance among farmers and local extension departments in the Lower Bengal Delta. This farmer cantered innovation will be more suitable and sustainable than that a pre-designated CIS concept without community interaction in any hydroclimatic settings.

6.5 Societal Contribution

In this dissertation, I organized iterative training for farmers and extension officers to improve their understanding of probabilistic forecast and to build trust in forecast information considering forecast uncertainty over a crop season (~4 months). Finally, this has led to a positive change in farming decisions through scientific forecast uptake. Currently, the trained farmers rely on – and do not feel comfortable without scientific forecasts for taking agricultural decision-making. This gained a positive social change regarding climate-smart decision-making of smallholders. A similar impact can be achieved elsewhere if CIS is co-created with farmers through training and capacity building.

A feedback mechanism is needed for service updates based on feedback from end-users (Ofoegbu and New, 2021, Sarku et al., 2020b). This research presents a co-production framework for feedback collection, interaction, and evaluation processes that can be useful hydrometeorological agencies. Besides, the national hydrometeorological agencies can use this framework to update their local policy agenda for addressing local needs. I draw attention to this, as it will ensure improving service delivery and better uptake of CIS at local levels. Also, the hydrometeorological departments could have a short training program for agricultural extension staff and farmers leaders to better understand forecast information and uptake considering uncertainties.

Women play a significant role in households and farm-scale agricultural activities. However, increasing climate risk is a key concern for both men and women smallholders (Rengalakshmi et al., 2018). Thus, I ensured men and women participation in the co-production process. I found that a participatory co-production process can accommodate both men and women farmers' information needs for day-to-day farm and non-farm activities. Most importantly, short-term and medium time-scale forecasts help them managing livestock, crop processing, and farm assets, and even more so in case of extreme events. Participants also noticed that after engaging in FFS; they contributed more to farm-related decision-making at the household level. FFS farmers reported that their community leadership improved after learning mobile applications for forecast access and dissemination. Learned farmers felt their respectful position in society enhanced while disseminating cyclone information with a 7- and 14-day time-scale.

For this dissertation, I am involved in an interaction process over the last 4 years. I found that social unity and decision-making have improved among experimental farmers. For example, farmers now frequently ask forecasts information on crop advisory services using a smartphone and social media. At the same time, trained extension officers have also been sharing agricultural advisory proactively on their social media pages. Furthermore, I observed that local extension officers organized meetings with and planned and implemented visit plans to farmers using the virtual platform *'Farmers Weather Club.'* This indicates not only an improved awareness and behavioral changes of farmers towards informed decision-making but also increased demand and access to agricultural extension services using ICT tools. In other words, the agricultural CIS demand is increasing after participatory co-production using the FFS approach and that can be achieved more and more in the society for protecting the smallholder farmers who play a vital role in food security in society.

During co-production, the *'Farmers Weather Club,'* has been developed where extension officers, agronomists, climate scientists, reporters, government officers, and end-users were and are actively involved. This platform has been created as an example of CIS in southwest Bangladesh. Besides, after receiving CIS training, the extension officers and farmers' trainer (FT) have been conducting similar training programs with farmers for improving climate information services in southwest Bangladesh. Some exposure visits have already been conducted by the agricultural extension department and their farmers' groups for developing participatory CIS in other areas of the Bengal Delta.

The Government of Bangladesh has been formulated several national policies to adapt to climate change impacts and sustainable agricultural development in the country. For example, the National Adaptation Plan of Action 2005, updated in 2009; the Bangladesh Climate Change Strategy and Action Plan 2008, updated in 2009; the Master Plan for Agriculture in Southern Region 2013 - 2021; the

Coastal Development Strategy 2006; the Bangladesh Delta Plan 2100, the Perspective Plan, the new 8th Five Years Plan, etc. All these plans have addressed the priority agenda for improving sustainable food production and climate change adaption. This research is highly relevant to the above policy agenda and the local adaptation needs of smallholder farmers and their agricultural livelihood in the Bangladesh Delta. Better CIS will improve farmers' decision-making, climate action, and climate-smart agricultural development in the Bangladesh Delta.

The local extension department and farmers jointly initiated the *'Farmers Weather Club'* based on research output. This information platform has been 'WaterApps Innovation' to support smallholders and local extension departments through co-production, Learning from this project could be used co co-designed platform in other geographical settings. This project's results have been disseminated not only in scientific journals, but also to the broader scientific and non-scientific communities publishing video documentaries, and popular publications and blogs, and joint activities with DeltaCap and CIMMYT-CSRD projects.

In summary, this dissertation has addressed the participatory co-production process using the farmer field school approach (FFS). This has improved farmers' capacity to uptake information through participatory learning at field school weekly interactions for better livelihood decision-making. Therefore, national and international organizations that are actively involved and responsible for developing climate services for smallholders can initiate participatory CIS co-producing replacing their existing top-down non-participatory approach. The Global Framework for Climate Services (GFCS) calls for the development of the National Framework for Climate Services to support vulnerable communities in developing worlds. This dissertation will help scientists for the development of the National Framework for Climate Services, especially in developing countries.

6.6 Future Outlook

I would like to address further investigation and research on public-private interest and co-designing of insurance packages for smallholder farmers in this future outlook. Business scale co-development of insurance packages combined with CIS requires solid research with involvement from the government or public-private partnerships such as banks and microfinance organizations. Investments are also needed to explicitly focus on building and increasing the farmers' awareness and capacity towards weather and climate-related phenomena by providing training, initiating weather schools, and organizing workshops on concepts regarding salinity increase, water management, weather, and climate-related phenomena concerning land-use activities. Adaptive decision-making should be seen as a participatory process that includes active engagement and empowerment of farmers, key stakeholders, researchers, and governmental and private organizations with the knowledge and capacity to uptake the outputs of participatory weather and climate information services. To this aim, the Bangladesh Agricultural Research Council and or Krishi Gobeshona Foundation, Agricultural Extension Offices (such as DAE and AIS, SRDI, etc.) of Bangladesh are called to play a significant role as they have the network and resources to support and upscale the services and contribute to sustainable agriculture.

I followed a bottom-up participatory process to bridge gaps between scientists and farmers. The local agricultural extension department was highly interested and participated through their field officers. However, the meteorological department (BMD) could not be engaged with their limited workforce in the weekly interaction sessions. Local BMD offices also have no mandate to participate in such a co-production collaborative process without project partnership at the national level. Therefore, BMD and BWDB could not share advance forecasts from their local offices with farmers as Therefore, an important next step is addressing this gap through organizing the national level workshop and multi-stakeholder meetings to initiate a national level partnership with DAE, BMD, BWDB, etc. to upscale CIS co-production process with smallholders. In the next two years, I will be involved in upscaling the *'Farmer Weather Club'* further in five Bangladesh districts and to test a farmer support smartphone application in coordination Space-Wek (Ghana), Meteoblue (Switzerland), Wageningen University. I will be working on behalf of Khulna University with active collaboration with the local extension department, Bangladeshi regional agricultural universities, BMD, and most of all, the innovative and climate-vulnerable smallholder farmers in five climate hotspots in the Bengal Delta.

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Supplementary Materials

Supplementary Materials 2A: Climate Data Analysis

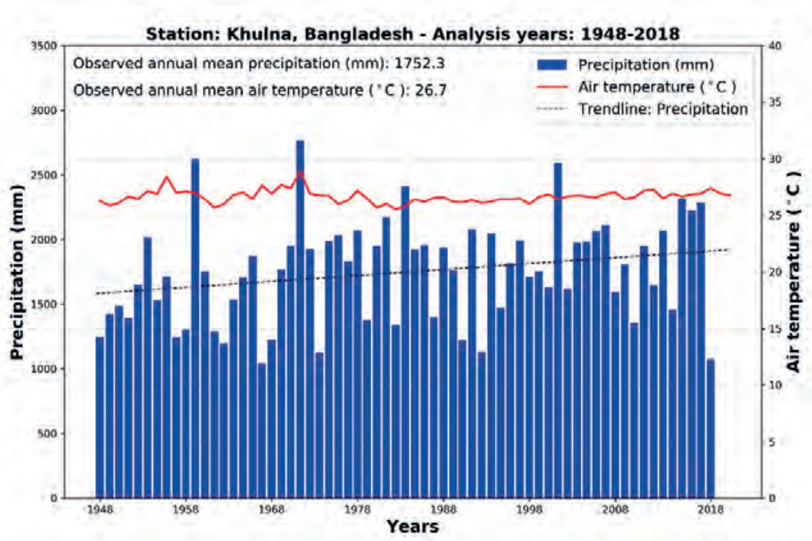

Figure 2A.1. Mean annual air temperature (°C) (red line) and mean annual precipitation (mm) (blue bar plots) for the period 1948-2018 for Khulna station in Bangladesh.

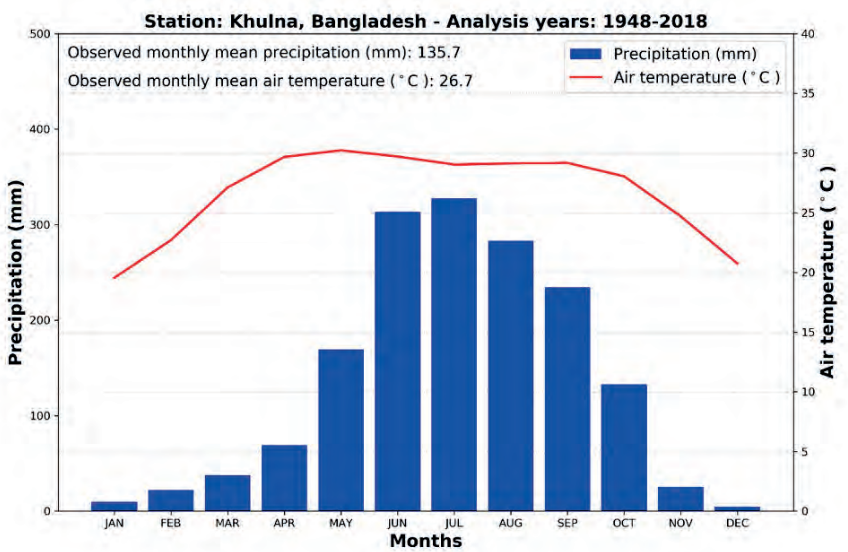

Figure 2A.2. Monthly mean air temperature (°C) (red line) and monthly mean precipitation (mm) (blue bar plots) for the period 1948-2018 for Khulna station in Bangladesh.

Climatology of Khulna

According to Köppen-Geiger classification (Peel et al. 2007), Khulna's climate is characterized as tropical (Aw). The summer period receives plenty of rainfall, while during the winter this is very little. The climatological data were obtained from Bangladesh Meteorological Department (BMD) and concern daily values of precipitation and air temperature were analyzed for the period of the years 1948-2018. Data were analyzed using the open-source programming language Python 2.7. According to the climatological data analysis, the mean annual precipitation is 1752.3 mm and is presenting a significant increasing trend since the beginning of the analysis period. Mean monthly precipitation is 135.7 but the months May-October contribute more than 90% of this amount. July is the month with the highest precipitation rate (327.6 mm), while December receives the least amount of precipitation within the year with 4.5 mm.

The mean annual air temperature for the period 1948-2018 for Khulna, Bangladesh is 26.7^{o}C and it is presenting an increasing trend since the beginning of the analysis period, while the mean annual minimum and maximum air temperature is 21.9 ^{o}C and 31.3 ^{o}C, respectively. January is the coldest month of the year with a mean minimum temperature of 12.9 ^{o}C, while April is the warmest month of the year with a mean maximum temperature of 34.9 ^{o}C.

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Supplementary Materials 2B

Baseline Farmers Interviews

Dear Sir/Madam, Greetings from Khulna University. We are Sadia and Sharmishtha, MSc Researcher of Env. Sci. Discipline. This interview questionnaire is designed to understand water and weather stresses and information needs of the peri-urban farmers of Khulna on behalf of the PhD action research, Water Information Service for Sustainable Agriculture (WaterApps). This research has academic objective for which your individual opinion is very important. We assure you that your recorded opinion will be used for research purpose only having no other financial or business objective. We assure you that there is no risk associated with your participation in this interview and there is no direct benefit to you for participation. It is anticipated that the information generated from this discussion will contribute to our action research project. You are free to decline any question(s) that you do not want to answer. You are also free to stop participating in this interview if you feel uncomfortable with any question. Do not hesitate to interrupt the interviewer for any reasons. Do you have any questions concerning this interview?

- ◯ OK

1. Respondent Location/ অবস্থান

1a. Are you agreed to participate in the interview/সাক্ষাৎ দিতে আপনার সম্মতি আছে?

- ◯ Yes
- ◯ No

1b. GPS Location

GPS coordinates can only be collected when outside.

latitude (x.y °)

____

longitude (x.y °)

____

altitude (m)

____

accuracy (m)

____

1c. Name of the village/গ্রামের নাম

- Sreefaltala
- Ilomra
- Teara
- Jharbhanga
- Baingamari
- Sanchibunia

1d. Name of the Upazila/উপজেলা নাম

- ◯ Rupsa
- ◯ Batiaghata

100. Demographic Information/জনতত্ত্ব

101. Name of the respondent/আপনার নাম কি?

____

102. Contact/Mobile No./মোবাইল নম্বর

____

103. Gender/জেন্ডার

- ◯ Male
- ◯ Female

104. Age of respondent/আপনার বয়স

____

105. Education/শিক্ষা গত যোগ্যতা

- ◯ Primary
- ◯ Secondary
- ◯ S.S.C
- ◯ H.S.C
- ◯ Graduate
- ◯ Moktob/Hafezi
- ◯ Can sign
- ◯ Illiterate

106. Type of family/ফ্যামালি ধরন

- ◯ Nuclear (single marital unit)
- ◯ Extended (more than one marital unit)
- ◯ Incomplete (no marital unit)

107. Household population/আপনার পরিবারে সদস্য সংখ্যা কত?

108. How long have you been involved in agricultural activities?আপনি কত বছর কৃষি কাজের সাথে জড়িত?

____

109. Monthly farm income of the household/ আপনার মাসে কৃষি আয় কত ?

____

110. Do you have income source other than agriculture? কৃষি আয় ছাড়া আপনার অন্যান্য আয় আছে কিনা?

- ◯ Yes
- ◯ No

111. Name of alternative income sources/ অন্য আয়ের প্রধান উৎস কি ?

____

112. Monthly income from alternative sources/ অন্যান্য উৎস থেকে আপনার মাসে আয় কত ?

____

113. Monthly household expenditure/পরিবারের মাসে খরচ কেমন?

- ◯ Expenditure and income are almost same
- ◯ Expenditure greater than income
- ◯ Expenditure less than income
- ◯ No reply

114. Household land size (decimal)/আপনার বাড়ির জমির পরিমাণ কত?

____

115. Household structural condition/আপনার বাড়ির ধরণ কেমন ?

- ◯ Pucca
- ◯ Semi-pucca
- ◯ Kancha

116. Latrine used by the household members/আপনার বাড়িতে কেমন টয়লেট আছে?

- ◯ Sanitary
- ◯ Pucca (but not water sealed)
- ◯ Pit (Not water sealed)
- ◯ Kancha/hanging
- ◯ No latrine at HH

117. Amount of personal land for agriculture (decimal)/ আপনার নিজস্ব জমির পরিমাণ কত?

____

118. Amount of leased land (in decimal)/আপনার মোট বর্গা জমির পরিমাণ কত?

____

119. What do you cultivate in Khariff-I/Aus season/আউস সিজনে আপনি কি ফসল চাষ করেন?

____

120. What do you cultivate in Khariff-II/Aman season? আমন সিজনে আপনি কি ফসল চাষ করেন?

____

121. What do you cultivate in Rabi season? রবি সিজনে আপনি কি ফসল চাষ করেন?

____

200. Domestic Water Supply/গার্হস্থ্য পানি সরবরাহ

201. Drinking water source/খাবার পানির উৎস

- ☐ Pipe water supply
- ☐ Shallow tubewell (<100m deep)
- ☐ Deep tubewell (>100m deep)
- ☐ River/canal/ponds
- ☐ Rainwater

202. Distance of the drinking water source from household (m)/বাসা থেকে খাবার পানির উৎসের দূরত্ব কত মিটার?

____

203. Frequency of drinking collection in a day/এক দিনে কতবার খাবার পানি আনেন?

____

204. Amount of collection per trip in liter/ একবারে কত লিটার পানি আনেন?

____

205. Responsible person for drinking water collection/ সাধারণত কে পানি আনেন?

- ☐ Adult male
- ☐ Adult female
- ☐ Children male
- ☐ Children female
- ☐ Old person

206. Quality of the drinking water/খাবার পানির গুণগত মান কেমন?

- ○ Very good
- ○ Good
- ○ Acceptable
- ○ Poor
- ○ Very poor

207. Cooking water source(s)/ রান্নার পানির উৎস কি?

- ☐ DTW
- ☐ STW
- ☐ River/Canal/Pond
- ☐ Rainwater
- ☐ Pipe water supply

208. Water source for HHs washing, bathing and sanitary uses/ বাসায় স্নান/টয়লেট/পরিষ্কার করার পানির উৎস কি?

- ☐ DTW
- ☐ STW
- ☐ River/Canal/Pond
- ☐ Rainwater
- ☐ Pipe water supply

209. Number of diarrhea incidence in the family during last 3 months/ গত ৩ মাসে বাড়ির কতজন ডায়রিয়ায় আক্রান্ত হয়েছে?

____

210. Number of diarrhea incidence in the family during last 6 months/ গত ৬ মাসে বাড়ির কতজন ডায়রিয়ায় আক্রান্ত হয়েছে?

211. Number of diarrhea incidence in the family during last 12 months গত ১২ মাসে বাড়ির কতজন ডায়রিয়ায় আক্রান্ত হয়েছে?

____

212. How do you rate drinking water scarcity? খাবার পানির সমস্যা কেমন?

- ◯ High
- ◯ Medium
- ◯ Low
- ◯ None

213. Particular time of drinking water scarcity/বছরে কোন সময় খাবার পানির সমস্যা বেশি হয়?

____

214. Do you harvest rainwater for drinking, domestic or irrigation uses? আপনি কি খাবার/কৃষি/বাসার জন্য বৃষ্টির পানি সংগ্রহ করেন?

- ◯ Yes
- ◯ No

215. Harvested rainwater is used for ..../সাধারণত কি কাজের জন্য বৃষ্টির পানি সংগ্রহ করেন?

- Drinking
- Domestic uses
- Irrigation
- Both drinking and domestic uses
- Both domestic and irrigation uses.
- All the above

216. How do you store rainwater? বৃষ্টির পানি কিসে সংগ্রহ/সংরক্ষণ করেন?

- Plastic/steel pot (i.e. bucket)
- Earthen pot
- Plastic tank
- Concrete tank
- Constructed pond/canal
- Natural pond or canal
- Others method

216a. if other method

217. What constrains do you face for rainwater harvesting?/বৃষ্টির পানি সংগ্রহ করতে কি ধরণের সমস্যা হয়?

____

300. Water for Agriculture/কৃষি জল

301. How do you rate agriculture water scarcity in this village? /এই গ্রামে কৃষি কাজের পানির অভাব/সমস্যা কেমন?

- ◯ High
- ◯ Moderate
- ◯ Low
- ◯ None

302. What are the major sources of agriculture water? কৃষি কাজের জন্য পানির উৎস কি?

- ☐ River/pond/canal (surface water)
- ☐ Groundwater (shallow:<100m)
- ☐ Groundwater (deep: >100m)
- ☐ Rainwater
- ☐ Wastewater/grey water

303. Please mention particular time of irrigation water scarcity? বছরে কোন সময় কৃষি কাজের পানির অভাব/সমস্যা বেশি হয়?

____

304. How often do you faced failure in expected production due irrigation water scarcity? কৃষি কাজের পানির অভাব/সমস্যা কত ঘনঘন হয়?

- ◯ Frequently (every year)
- ◯ Occasionally (in some year)
- ◯ Rarely (after few year)
- ◯ Never

305. What is the main cause of irrigation/agriculture water scarcity? কৃষি কাজের পানির অভাব এর প্রধান কারণ কি?

____

306. What do you do when you face irrigation/agriculture water scarcity? কৃষি কাজের পানির অভাব হলে কিভাবে মোকাবেলা করেন?

____

307. Method of irrigation/কি প্রক্রিয়াই সেচের পানি দেন?

- ☐ Surface Irrigation or flooded irrigation
- ☐ Overhead or Sprinkler Irrigation
- ☐ Drip or Trickle Irrigation

308. Distance of the irrigation water source from the crop field (m)/ মাঠ থেকে সেচের পানির উৎস কতদূরে?

____

400. Water and Weather Stresses/আবহাওয়া এবং জল নিয়ামক প্রভাব

401. How often water and weather stresses damage or impact on your crop production? জল-আবহাওয়া সমস্যা জনিত কারণে কত ঘনঘন ফসল নষ্ট হয়?

- ○ Almost always
- ○ Often
- ○ Sometimes
- ○ Seldom
- ○ Never

402. What are major water and weather hazards for your crops? জল ও আবহাওয়া জনিত প্রধান ঝুঁকি গুলো কি কি?

____

403. What do you do in response to water and weather stresses? জল ও আবহাওয়া জনিত প্রধান ঝুঁকি গুলো কিভাবে মোকাবেলা করেন?

____

500. Access to (weather and water) information/ আবহাওয়া এবং জল তথ্য গমনাগমন

501. How much are you dependent on water and weather information for agricultural decision-making? কৃষি কাজে সিদ্ধান্ত নিতে জল ও আবহাওয়া তথ্যের উপর আপনি কতটা নির্ভরশীল?

- ○ Almost always
- ○ Often
- ○ Sometimes
- ○ Seldom
- ○ Never

502. Which information is needed for your crop related decision-making? কৃষি কাজে সিদ্ধান্ত নিতে কি কি তথ্য দরকার হয়?

____

503. How do you access weather and water information at present situation? | বর্তমানে আপনি কিভাবে আবহাওয়া এবং পানির তথ্য কিভাবে পেয়ে থাকেন?

- ☐ TV
- ☐ Radio
- ☐ Newspaper
- ☐ Mobile (sms, voice call, app)
- ☐ Peer farmers
- ☐ DAE officer
- ☐ Others (specify)

503a. If other, specify

____

504. Quality of the available weather and water information at present situation? বর্তমানে জল ও আবহাওয়া তথ্য এর মান কেমন?

- ◯ Very good
- ◯ Good
- ◯ Acceptable
- ◯ Poor
- ◯ Very poor

505. How existing weather and water information services could be improved? বর্তমান জল ও আবহাওয়া তথ্য এর মান কিভাবে উন্নত করা যায়?

____

600. Information Needs/ তথ্য প্রয়োজন

601.Do you think that weather and water information are important for decision-making? আপনি কি মনে করেন জল ও আবহাওয়া তথ্য কৃষি কাজে সিদ্ধান্ত নিতে দরকার?

- ◯ Strongly Agree
- ◯ Agree
- ◯ Undecided
- ◯ Disagree
- ◯ Strongly Disagree

602.What kind of information is needed for crop related key decision-making? কৃষি কাজে সিদ্ধান্ত নিতে আবহাওয়া বিষয়ক কি কি তথ্য দরকার?

- [ ] Rainfall
- [ ] Temperature
- [ ] Humidity
- [ ] Cyclone/Storm surge
- [ ] Hailstorm
- [ ] Fog
- [ ] Others (specify)

602a. If others, then tell about specific weather information which you need?

____

603. What kind of water information is needed for crop related key decision-making? কৃষি কাজে সিদ্ধান্ত নিতে জল বিষয়ক কি কি তথ্য দরকার?

- [ ] Salinity of water
- [ ] Soil salinity
- [ ] River discharge
- [ ] Flood forecast
- [ ] Others

603a. If others, then tell about specific water information which you need? অন্যান্য হলে নির্দিষ্ট করে বলেন

____

604. What other information is needed for your crop related key decision-making? এছাড়াও অন্য কোন তথ্য দরকার বলে মনে করেন ?

____

605. How advance information is needed for crop related decision-making? প্রয়োজনীয় তথ্যগুলো কত আগে হলে সিদ্ধান্ত নিতে ভাল হয়?

- [ ] Real-time
- [ ] 1-day advance
- [ ] 2/3-day advance
- [ ] 1-Week advance
- [ ] 2-Weeks advance
- [ ] 1-Month advance
- [ ] 3-Months/Seasonal

606. Will you be interested to join us for developing information platform in future? প্রয়োজনীয় তথ্যগুলো উন্নয়নে আপনি অংশ নিতে ইচ্ছুক ?

- ◯ Agree
- ◯ Disagree

607. What changes have you been observed in weather and climate condition? এই এলাকায় আবহাওয়া ও জলবায়ু জনিত পরিবর্তন গুলো কি কি?

____

608. How local farmers are knowledgeable to understand local weather phenomenon in advance? কৃষক আবহাওয়ার ও জলবায়ু জনিত ঘটনাবলী আগে বুঝতে কতটা সক্ষম?

- ◯ Excellent
- ◯ Somewhat
- ◯ Poor

609. Do they use any local indicators? কৃষক কি কোন নির্দেশক/সূচক/ইঙ্গিত ব্যবহার করে?

- ◯ Yes
- ◯ No

610. What are the local indicators used by farmers? কি কি নির্দেশক/সূচক/ইঙ্গিত ব্যবহার করে?

____

700. Use of mobile phone and apps/মোবাইল ফোন এবং অ্যাপস ব্যবহার

701. Do you use mobile phone?আপনি মোবাইল ব্যবহার করেন?

- ◯ Yes
- ◯ No

702. Do you have smartphone (or in the family)? আপনি বা পরিবারের কেউ স্মার্টফোন ব্যবহার করেন?

- ◯ Yes
- ◯ No

703. Do you use mobile phone for agricultural information? আপনি কি কৃষি তথ্যের জন্য মোবাইল ফোন ব্যবহার করেন?

- ◯ Yes
- ◯ No

704. What type of information is received by mobile phone? কি জাতীয় কৃষি তথ্যের জন্য মোবাইল ফোন ব্যবহার করেন?

- Weather information
- Fertilizer or pesticide application
- Crop disease and control advice
- Price of input (fertilizer, pesticide, seed etc.)
- Market price of crop
- Others (specify)
- Not aplicable

705. How do you get agri information by mobile phone? মোবাইল ফোনে কিভাবে কৃষি তথ্য পান?

- Dial number
- SMS/MMS
- Helpline/Call Centre
- From internet/website
- Mobile apps
- Others (specify)
- Not applicable

706. If mobile app, then which type of the apps? যদি অ্যাপ হয় কি ধরেনের অ্যাপ?

- ☐ Weather/climate apps
- ☐ Farm management apps
- ☐ Agriculture news apps
- ☐ Disease and pest apps
- ☐ Market data apps
- ☐ Don't use mobile app for information

707. How easy to find specific agriculture information using mobile apps? মোবাইল অ্যাপ দিয়ে তথ্য পাওয়া কতটা সহজ?

- ◯ Very easy
- ◯ Easy
- ◯ Neutral
- ◯ Difficult
- ◯ Very difficult
- ◯ Don't use apps for information
- ◯ Don't know about mobile apps

708. What factors limit use of mobile apps by farmers? কি কারণে মোবাইল অ্যাপ এর ব্যবহার কৃষকদের মধ্যে সীমাবদ্ধ?

- ☐ Economic
- ☐ Unsuitable
- ☐ Incompatible design
- ☐ Lack of ICT knowledge
- ☐ Internet unavailability
- ☐ Don't have smartphone
- ☐ Others (specify)

708a. if others, specify

____

709. Would you be interested to use agricultural apps, if we initiate for you? আপনি কি মোবাইল অ্যাপ ব্যবহার করতে আগ্রহী হবেন?

- ◯ Yes
- ◯ No

710. If yes, which format will you prefer? তথ্যের ফরম্যাট কেমন হলে ভাল হয়?

- ☐ Text format
- ☐ Photograph/image/diagram
- ☐ Audio-vedio
- ☐ Others (specify)

710a. if other, specify

____

711. What would be the best way to communicate weather/water information with farmers? কৃষি তথ্যের জন্য কি যোগাযোগ মাধ্যম ভাল বলে মনে করেন?

____

712. How frequently? কত ঘনঘন তথ্য হলে ভাল হবে?

____

Give Thanks

OK

Thanks for your kind patience ! Many Thanks !

Supplementary Materials 2C

FGD Discussion Form

Rapporteur Notes: Name of the Rapporteur: Sharmishtha Roy/Sadia Ashraf/Uthpal Kumar

A. General information	**Responses/comments**
Date	
Location of the FGD	
Consent of participation	
GPS location	
Field Facilitator	
Participants	
Introduction	
B. Cropping practices	
1. Who is the landholder and who is the decision-maker?	
2. Discuss farming practices of the peri-urban farmers (single, multiple, integrated)	
3. Prepare seasonal crop calendar in a participatory way (PRA)	
4. Discuss how local farmers take decisions for crops during different crop seasons	
C. Access to water information for agriculture	
5. Discuss the importance of information and existing information services for agricultural practices	
6. At present how peri-urban farmers access to water-related information service? • Where they get information? • How often? • How advance?	
7. How and who communicate that information with local farmers?	
8. How effectively communicated that information with local farmers?	
10. What are the major limitations of currently available water and weather information services in the study area?	
11. Which factors (traditional, social, economic, environmental) influence agricultural decisions?	
D. Traditional knowledgebase of peri-urban farmers?	
12. How local farmers are knowledgeable on weather and climatic forecast? What	

capacity do they need to better understand forecast and information	
13. Do they currently use/apply traditional knowledge for the agricultural decision? If yes, types of traditional/local knowledge, indicators are used/applied for agricultural decision-making	
14. Discuss the usefulness of traditional information forecast and compare preferences with scientific forecast	
15. Who acts on that information? How do they act on those information bases made by the traditional knowledge system?	
16. What are the major limitations of the traditional knowledge/ forecast system for taking the agricultural decision?	
17. How scientific forecast knowledgebase could be improved with local observation?	
18. How local knowledgebase could be improved based on scientific forecast information?	
E. How do they currently do or adapt to weather and water stresses	
19. Discuss how local farmers adapt to weather variability, climate change, water stress, land-use change, and changes in socio-economic aspects of their livelihoods in the peri-urban context?	
20. How diversified and adaptive are the local incomes and livelihood opportunities of the farmers?	
21. Discourse major threats of livelihood of the peri-urban farmers?	
22. How do farmers see their future/crop production activities in this area?	
Thanks	

Supplementary Materials 2D

Expert Interview Form

Interviewer: Uthpal Kumar, Ph.D. researcher, WUR, the Netherlands.

Date: ....../....../2018 Time:.........

Issue/Discussion points	**Responses/comments**
Introduction with the Expert Information is the key input for agriculture. Water and weather information is crucial for farming decisions. Hereby, we intended to take your valuable response and opinion for the research entitled, 'Tailor-made water information service for sustainable agriculture in peri-urban Ganges Delta of Bangladesh'. This research aims to tailor water information services for farmers in peri-urban Khulna in a participatory manner. By this form, I will ask about services that you are already providing to the farmers. I will also ask about major challenges that you are facing regarding your services. Finally, I will ask about how to co-design an innovative platform for farmers using ICT tools.	
Name of the Expert/Interviewee	
Email ID/Mobile	
Designation/Responsibilities	
Name of the Organization	
Interview Method	
1. Who are the primary users/customers of your services?	
2. What services do you provide to the farmers?	
3. Do you provide information services to the farmers?	
4. Which media/technology do you use for interacting with farmers?	
5. What are the sources of the information that you provide to the farmers?	
6. How advance/lead time information do you provide to the farmers and other groups if any?	
7. Do farmers take the decisions for crops based on your information services? 7a. how do you know that? (any M&E?)	
8. How effective/useful that information for crop-related activities/decision-making to the farmers? 8a. For example: which types of decision-making?	
9. What factors influence the uptake of your information services?	
10. What factors limit the uptake of your information services?	
11. Did you involve users in the design	

phase of your service?	
12. Is there any feedback mechanism from the users? For example: from end-users/ intermediaries	
13. Did you assess needs before design your services? 13a. What are the processes?	
14. How do you notice the importance of water-related information for agricultural decision-making?	
15. How farmers depend on water-related information in the present situation?	
16. Currently how often farmers access information services from you? 16a. How advance?	
17. What capacity do you need to improve information services to the farmers?	
18. What capacity do farmers need to better uptake of your information services?	
19. Could you discuss the usefulness and limitations of traditional information sources and compare preferences with scientific forecast information?	
20. What are the major challenges for developing information services for farmers?	
21. Discourse major threats that impact the livelihood of the peri-urban farmers	
22. How do you see farming future/crop production activities in peri-urban areas?	
23. Do you have any other comments on information services for farmers?	

Thank you very much for your time for this research

Interview Summary/Main discussion points:

Supplementary Material 3A

(Farmers baseline / end-line needs assessment questionnaire)

Key Research Question

(1) what kind of information is needed by the delta farmers, and (2) whether information needs change over time following capacity building during co-production of information services?

1) Farmer's Personal Information

1.1 Name	1.2 Gender	1.3 Village	1.4 Upazila	1.5 Contact no

No.	Questions	Likert scale: 1-2-3-4-5: [strongly disagree to strongly agree]
1	Do farmers need climate information services for agricultural practices and decision-making?	
2	How current agricultural practices are climate-sensitive?	
3	How do you rate your consciousness level for the collection of climate information for agricultural practices and decision-making?	

The following questions I will repeat to understand changes in weather formation needs of peri-urban farmers before and after capacity building.

4. What kind of weather information are useful for crop-related key decision-making?

For each type of information, need to indicate your judgment according to the five points scale

Weather information needs (Survey 2018)	After interactions and capacity building (2019)

5. What kind of water information are useful for crop-related key decision-making?

Water-related information needs (Survey 2018)	After interactions and capacity building (2019)

6. What should be the lead-time for forecast information?

Led-time information needs (Survey 2018)	After interactions and capacity building (2019)

7. How do you rate your knowledge of local weather?

Farmer's knowledge of local weather (Survey 2018)	After interactions and capacity building (2019)
	• Old farmers: • Middle age farmers: • Young farmers: • Women farmers

8. What should be the preferred communication platform for sharing weather and water information?

Preferred communication platform (Survey 2018)	After interactions and capacity building (2019)
	Group contact: FFS all farmers • Mobile phone: (call, app, social media)- mostly young and middle age farmers • Traditional Media: Radio, TV, Newspaper

9. Are you interested in receiving weather information using a mobile app?

Interested for an app platform	After interactions and capacity building (2019)

10. Which format would be more useful to understand forecast information?

Format of information (baseline survey 2018)	After interactions and capacity building (2019)
	• Text in Bengali • Picture format • A picture with Bengali explanation

11. What are the major limitations to access weather information to you?

Limitation to access weather information by farmers (baseline survey 2018)	After interactions and capacity building (2019)

	• Lack of useful/quality information • Lack of understanding forecast • Lack of communicated • Lack of ICT knowledge

12. How do you rate the quality of the current weather information service?

Quality of available weather information (baseline 2018)	After interactions and capacity building (2019)

13. Do you agree weather information needs are different among the following farmers' groups

Are information needs are different among farmers (baseline 2018)	After interactions and capacity building (2019)
• Paddy farmers • Vegetable farmers • Integrated farmers • Livestock farmers • Aquaculture farmers	

13. Seasonal scale forecasts can enable strategic and tactical decision-making for farmers such as the selection of crop, seed variety, long-term preparation, and mitigation. We identified a total of 14-key decision points during the baseline study. Now we want to explain more detail about information needs for specific decisions, preferred way and communication platform(s) for information with and for farmers in Khulna (14-key decisions reported in paper 1)

Table 2: Farmers' key decision steps and information needs for improving current agricultural practices and cropping plan decision-making (assess by FGD)

		What	When	How	By whom	Remark/explanation
Sl.	Key decisions points (found from baseline study 2018 - Kumar et al 2020)	Information needs for particular key task/decision	How advance / lead-time information would fulfill your needs and interest? ▪ Real-time ▪ Short-term (up to 1-Week) ▪ Medium-term (2-4 Weeks) ▪ Seasonal scale (3-Months)	Preferred platforms	Producer/extension/researcher frequency of information communication	How it would improve farmers' ongoing practices and decision-making?
1	Crop selection					
2	Land preparation					
3	Variety selection					
4	Hiring labor					
5	Acquiring inputs					
6	Seedling					
7	Transplant					
8	Irrigation					
9	Fertilizing					
10	Weeding					
11	Disease control					
12	Preparation - harvest					
13	Harvest and storage					
14	Selling/marketing					
	Others (if any)					

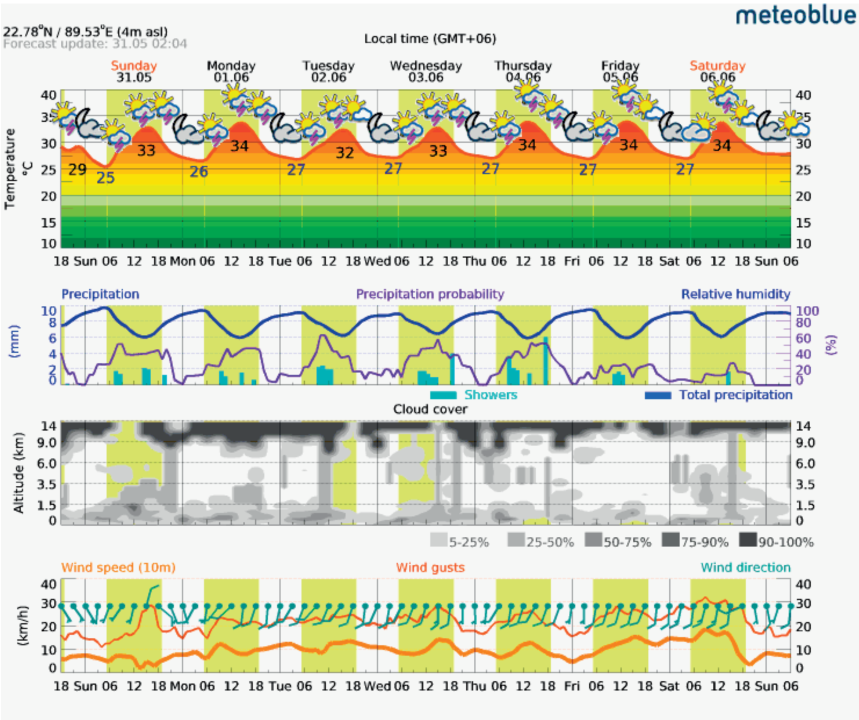
Supplementary Material 3B

Waterapps Climate School

Khulna, Bangladesh – meteoblue ensemble forecasts

1. Meteogram 7 days

http://my.meteoblue.com/visimage/meteogram_picto?lat=22.783&lon=89.533&apikey=599fc815bec5



This Meteogram shows the forecast for **7 days** for 4 different diagrams with variables in hourly intervals. The data is valid for the selected location and updated at least 2 times per day. The hour of the last update is written on the top left of the Meteogram, and below the coordinates. The Meteogram is presented in local time.

The 1st subplot depicts the **air temperature** (°C) (red color) and the **potential prevailing conditions** (sunny, cloudy, rainy, etc).

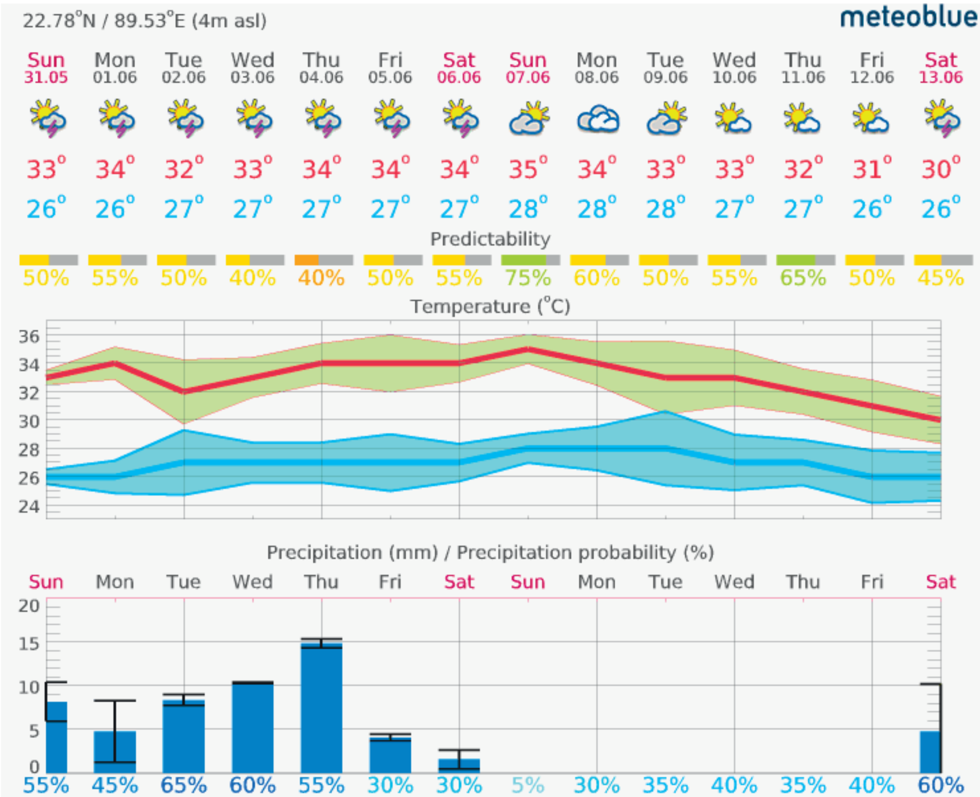
The 2nd subplot depicts the **total precipitation** (mm) (blue color) & **precipitation probability** (%) (purple color). **Rain showers** are also depicted with bar plots (turquoise color).

The 3rd subplot depicts the **cloud cover development probability** (grey color scale) at various altitudes (km).

The 4th subplot depicts the **wind speed** in 10m height (km/h) (orange color), **wind gusts** (km/h) (light red color) which refer to sudden increases of the wind's speed that last no more than 20 seconds, and **wind direction** (N-E-S-W) (cyan color).

2. Meteogram 14 day

http://my.meteoblue.com/visimage/meteogram_14day?lat=22.783&lon=89.533&apikey=599fc815bec5



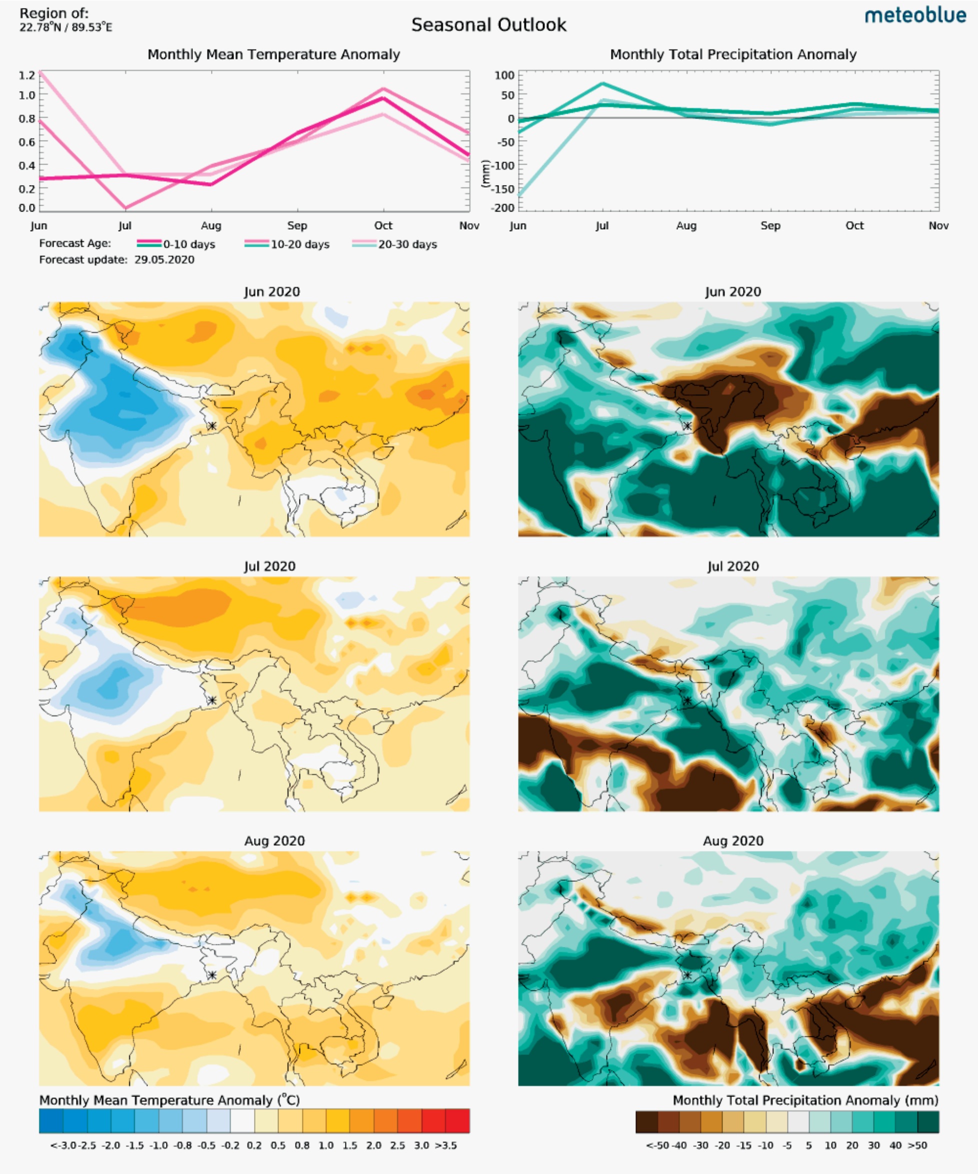
The Meteogram 14-days shows the weather forecast for the next 14 days period, with weather symbols and a range of maximum, average and minimum air temperature (°C).

Below is the weather predictability (%) and following that the range of maximum (red color) and minimum (light blue color) air temperature (°C).

At the bottom, **total precipitation** is depicted in bar plots (mm) (blue color) as well as **precipitation probability** (%) (blue color scale)

3. Seasonal forecast (image)

http://my.meteoblue.com/visimage/meteogram_seasonal?lat=22.783&lon=89.533&apikey=599fc815bec5



The seasonal climate data package delivers **regional anomalies** for the **next 3 months** for **precipitation** (mm) (left plots) and **air temperature** (°C) (right plots). It covers an area of 100km by 100km or larger. Anomalies are deviations from the climatological mean. The mean seasonal forecast data is computed by NOAA and ECMWF.

More information can be found here at source

https://content.meteoblue.com/en/specifications/weather-variables/predictability

Supplementary Material 3C

WaterApps Climate School – Farmers Field School (FFS) Protocol

A. Objectives:

- Informed agricultural decision-making
- Better uptake climate forecasts information
- Reduces loss and damages from climate hazards
- Manage climate risks, vulnerabilities and climate uncertainties for agriculture

B. Rules of school

- Duration: Mid-June to Mid-Nov (5 Months)
- Team: Farmers (25-30), Researcher (1), SAAO (1)
- Time for school: 1:30 hours (select suitable hrs that fits with majority farmers
- School Session: Weekly (select a suitable day that fits with majority farmers)
- Field Visit at BMD Khulna: 1 visit – half day

C. School Monitoring:

- Weekly agricultural advisory by SAAO
- Weekly session by SAAO
- Monthly visit by UAO/AEO
- Weekly task and feedback from farmers

D. Sharing forecast information: BMD/Meteoblue/Facebook/Others

E. Expectation of the farmers

- What is your main expectation/learning goal from this school?
- Game 1: Choose your own role number
- What would be your appropriate group choice?
  Paddy farmers (local),
  a. Paddy farmers (HYV),
  b. Homestead vegetables farmer,
  c. Livestock farmer, and
  d. Aquaculture farmer

Key questions for group work:

a) What information is needed?
b) For what decision/task?
c) How advance?

ওটারঅ্যাপ জলবায়ু স্কুল **(**WaterApps Climate School**)**

কৃষকের ঠিকানা (Farmers Address) কৃষক আইডিঃ

গ্রাম (Village): ব্লক (Block):

ইউনিয়ন (Union):

উপজেলা (Upazila): জেলা (District):

ব্যক্তিগত তথ্য **(**Personal Information**)**

কৃষকের নাম **(**Name of the Farmer):

জেন্ডার (Gender): বয়স (Age):

কৃষি কাজের অভিজ্ঞতা (Year of Agricultural Experience):

এই মৌসুমে আপনার ফসল সমূহ (Crop season)**:**

মাঠ ফসল (Field crops):

বসতবাড়ি ফসল (Homestead crop):

গবাদি প্রাণী (Livestock):

মৎস্য (Aquaculture):

অন্যান্য (Others-if any)

Supplementary Materials 4A

Weekly Monitoring Questions

Date........../.........../2019

The weekly session objectives are:

- Informed agricultural decision-making
- Better uptake climate forecasts information
- Reduces loss and damages from climate hazards
- Manage climate risks, vulnerabilities and climate uncertainties for agriculture

1. How was the forecast information (quality) of last week? Why do you think so?

2. What works? What did not? Specify on the following:
    a. Rainfall (amount: heavy, medium, light, duration, timing as of the forecast)
    b. Temperature (as of forecast, high, medium, low)
    c. Cloud cover (compare with forecast and you observed)
    d. Wind speed and wind gusts (compare with forecast you observed)
    e. Other emergencies that shared with you shortly

3. What was the main weather challenge/struggle last week for crop-allied activities?
4. What was the main forecast barrier/struggle to use forecast last week?
5. What strategies did you take to get rid from the specific weather struggle
6. At what extent strategies meet the specific weather struggle.

7. How many of you shared forecasts information with peer farmers?
8. Which information package did you discuss with peer farmers? Specify briefly.
    a. 7-days
    b. 14-days
    c. Seasonal
    d. All of them
    e. A general idea on rain, tem, cloud and wind
9. What response did you get from peer farmers? Do you see interest of peer farmers to access the forecast information? Explain

10. What did you do if you were absent last week at school?
11. Did it make any difference with or without forecasts? Explain why and how?
12. Are you still interested to continue school from next weeks? Why?
13. Any other specific questions raised by the participants

Supplementary_Materials_4B_

FFS_Evaluation_Quantitative_Interviews

PART A: General Questions

101. School name

- ◯ Basurabad
- ◯ Jharvanga

102. Name of the respondent

____

103. Gender of the respondent

- ◯ Male
- ◯ Female

104. Age group

- ◯ 20-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60 and over

105. Years of farming experience

- ◯ 0-10
- ◯ 11-20
- ◯ 21-30
- ◯ 31-40
- ◯ above 40

106. Percentage of income from agriculture (%)

- ◯ 0-20
- ◯ 21-40
- ◯ 41-60
- ◯ 60-80
- ◯ Above 80

107. Total cultivated land (1 acre = 100 decimal)

____

108. Ownership of the cultivated land

- ◯ Pesonal
- ◯ Leased
- ◯ Both (personal and leased)

108. Livelihood practices Kharif-II/Monsoon/T-aman season

- ☐ Pady (local)
- ☐ Paddy (HYV)
- ☐ Vegetables at homestead
- ☐ Vegetables at field
- ☐ Orchard
- ☐ Integrated farming (combining crops, aquaculture and livestock)
- ☐ Livestock
- ☐ Aquaculture
- ☐ Others (specify)

109. What is your other livelihood business?

____

PART B: Forecast source and use

201. Did you change agricultural decisions based on our forecasts?

- ◯ Yes
- ◯ No

If no why not?

____

202. Is there any difference in your farming decisions after participation in the weather school?

- ◯ Yes
- ◯ No

204. Do you follow the meteoblue forecast packages?

- ◯ Yes
- ◯ No

204a) How frequent?

- ◯ No – I did not follow later after the school
- ◯ I follow the forecast once in a week
- ◯ I follow the forecast 2-3 times a week
- ◯ I follow the forecast on a daily basis
- ◯ I follow the forecast several times in a day

204b) Please describe the reason for this specific choice

____

205. Do you currently take farming decisions based weather forecasts from the following sources?

- ☐ TV
- ☐ Radio
- ☐ Newspaper
- ☐ Peer farmers
- ☐ DAE

206. Do you currently base local knowledge/indicators/forecasts for farming decisions?

- ◯ Yes
- ◯ No

208. Do you combine scientific forecast and local knowledge/indicators for taking decisions?

- ◯ Yes
- ◯ No

210. Do you share forecasts with your family, relative and peer farmers?

- ◯ Yes
- ◯ No

210a. With family members?

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

210a) Why?

210a) How (oral, mobile, app)

- ☐ In person (oral)
- ☐ Mobile call
- ☐ Messenger (app)

210b) With relatives

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

210b) Why?

210b) How

- ☐ In person
- ☐ Mobile
- ☐ Messenger (app)

210c) With peer farmers

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

210c) Why?

210c) How

- ☐ Oral
- ☐ Mobile
- ☐ Messenger (app)

210d) With others (specify)

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

210d) Why?

210d) How

- ☐ Oral
- ☐ Mobile
- ☐ Messenger (app)

212a) I use indigenous forecast

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Vever

212a) Why?

212b) I use scientific forecast

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Vever

212b) Why?

212c) I use combined (scientific and local) forecast

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Vever

212c) Why?

PART C: Mode of Communication

301. How often do you like to receive forecast information?

- ☐ Daily
- ☐ Weekly
- ☐ Bi-weekly

301b) Why?

---

302. How would you rate overall forecast communication?

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Rate forecast lead-time 7-days

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Rate forecast lead-time 14-days

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Rate forecast lead-time seasonal

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Information content based on your needs

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Format of forecast (diagrams)

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Mode of communication: 1) Paper based

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Mode of communication: 2) Messenger app

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Mode of communication: 3) weekly meeting

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Mode of communication: 4) emergency forecast

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Forecast explanation by researcher

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Farmers participation in the school

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Feedback collection and scope

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Group sharing and learning outcome

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Flexibility for access to the forecast information

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302.Forecasts overall quality/accuracy

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Quality of the overall services (continuity of forecast information)

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Improved knowledge and capacity on forecast since beginning of the school

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

302. Increased uptake of scientific forecast information for decision-making

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

303. Do you face any problem for forecast communication and uptake?

- ◯ Yes
- ◯ No

303a) What are the problems?

____

PART D: Aspect of visualization

401. Do you understand forecast diagrams that we shared you?

- ◯ Not at all
- ◯ A little
- ◯ Medium
- ◯ Good
- ◯ Very much
- ◯ I don't know

402. How easy to understand forecasts to see those diagrams?

- ◯ Not at all
- ◯ A little
- ◯ Medium
- ◯ Good
- ◯ Very much
- ◯ I don't know

403. Which forecast diagram did you mostly use any why?

- ☐ Meteogram 7-days
- ☐ Meteogram 14-days
- ☐ Seasonal forecast
- ☐ None

403a) Why?

---

405. What is your overall understanding of the weather parameters from 7-days forecast diagram?

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405a. Maximum Temperature?

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405b. Minimum Temperature?

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405c. Shower?

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405d. Total precipitation/rainfall?

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405e. Relative humidity

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405f. Cloud cover

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405g. Wind speed

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405h. Wind gusts

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405i. Wind direction

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405j. Probabilities and predictibility

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405k. Was not useful because....

405. How the specific information was understandable from 14-days forecast

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405a. Maximum Temperature

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405b. Minimum Temperature

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405c. Total precipitation/rainfall

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405d. Indication of sunlight

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405e. Indication of thunder

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

405f. Probability/predictability percentage

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

g. Was not useful because.....

How the specific information was understandable from 3-months/seasonal forecast?

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

a) 3-months monthly mean temperature anomaly

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

b) 3-months monthly mean rainfall anomaly

- ◯ Very poor
- ◯ Poor
- ◯ Medium
- ◯ Good
- ◯ Excellent

c) Was not useful because....

PART E: Forecast quality (in) accuracy and decision-making

501. How would you rate overall forecasts quality that we shared with you?

- ◯ Not at all
- ◯ Little
- ◯ Medium
- ◯ Good
- ◯ Excellent

502. How often the forecasts products were inaccurate?

- ◯ Always
- ◯ Very often
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ Can't say

503. To what extent the weather phenomenon were larger or smaller than the forecasts?

- ◯ Higher than forecast
- ◯ Same as forecast
- ◯ Lower than forecast
- ◯ Not at all (inaccurate)
- ◯ Can't say

503a. Sunlight/Sunny day

- ◯ Higher than forecast
- ◯ Same as forecast
- ◯ Lower than forecast
- ◯ Not at all (inaccurate)
- ◯ Can't say

503a) Others?

____

503b. Temperature (Max/Min)

- ◯ Higher than forecast
- ◯ Same as forecast
- ◯ Lower than forecast
- ◯ Not at all (inaccurate)
- ◯ Can't say

503b) Other

____

503c. Shower/Rainfall

- ◯ Higher than forecast
- ◯ Same as forecast
- ◯ Lower than forecast
- ◯ Not at all (inaccurate)
- ◯ Can't say

503c) Other

503d. Cloud cover

- ◯ Higher than forecast
- ◯ Same as forecast
- ◯ Lower than forecast
- ◯ Not at all (inaccurate)
- ◯ Can't say

503d) Other?

503e. Wind speed & wind gusts

- ◯ Higher than forecast
- ◯ Same as forecast
- ◯ Lower than forecast
- ◯ Not at all (inaccurate)
- ◯ Can't say

503e) Other

---

504. How prepared do you feel with the forecast that you received from the weather school?

- ◯ Not at all
- ◯ A little
- ◯ Medium
- ◯ Good
- ◯ Very much
- ◯ I don't know

505. What is your overall trust on the forecasts that we shared with you?

- ◯ Not at all
- ◯ A little
- ◯ Medium
- ◯ Good
- ◯ Very much
- ◯ I don't know

506. If the shared forecast was not trustworthy, what decision did you take? [Multiple response possible]

- ☐ See different forecast
- ☐ Ask experienced peer farmers
- ☐ Turn to local/indigenous forecast
- ☐ Turn to my personal experience

506a. Other (specify).....

---

508. How participatory advisory services helped you for planning your weekly, bi-weekly, monthly and seasonal scale agricultural activities?

- ◯ Not at all
- ◯ A little
- ◯ Medium
- ◯ Good
- ◯ Very much
- ◯ I don't know

509. How do you rate your quality of decision-making using forecast?

- ◯ Not at all
- ◯ A little
- ◯ Medium
- ◯ Good
- ◯ Very much
- ◯ I don't know

PART F: Use of forecast for emergency response and disaster management

601. Did you get an indication of emergency weather events from the forecast diagrams?

- ◯ Yes
- ◯ No

602. How the forecast diagrams were useful to understand emergency weather phenomena in advance?

- ◯ Not at all
- ◯ A little
- ◯ Medium
- ◯ Good
- ◯ Very much
- ◯ I don't know

Thank giving

____

Name of the investigators

____

Supplementary Materials 4C

Specific on the forecast (using meteoblue products)

Date ..../................/2019

Name of the respondent:

PART B: forecast source and use

201. Did you change any agricultural decisions based on our forecasts?

YES or NO

a) If yes, what particular decisions were you changed based on forecasts?

Sl	Decision changed based on the forecast information
1	
2	
3	
4	
5	
6	
7	

b) What was the result? (Positive or negative; loss or benefits)

----

c) If no, what was the problem?

----

202. What are the differences in your farming decisions after participation in the weather school?

a) Before	b) After

203. List all agricultural and non-agricultural decisions that you took based on our forecasts. For example, start from land preparation then upto harvest, processing and storage.

a) agricultural decisions based on forecast	b) non-agricultural decisions based on forecast

205. Do you currently take farming decisions based weather forecasts from the following sources?

Forecast information sources	**Put √**	**How often?**	**Why? Why not?**
TV			
Radio			
Newspaper			
Oral communication with peer farmers			
DAE farmers network (FFS)			

206. Do you currently take farming decisions based on local knowledge/indicators/forecasts?

YES/ NO

What are those indicators?	**Farming decisions based on the specific indicator**	**Perception of accuracy (%)**

207. How do you compare local knowledge/indicators/forecast for farming decisions with scientific forecast that you had from the weather school?

Local knowledge	Scientific forecast

208. Do you combine scientific forecast and local knowledge/indicators for taking decisions?

YES / NO

209. If yes, explain for which specific farming decisions and how do you do that

----

----

211. What responses did you get from your family, relative and peer farmers?

a) Responses from family member**?** --
----

b) Response from relatives ---

----

c) Response from peers farmers ---

----

d) Others ---

PART C: Mode of Communication

303. What problems do you face for forecast communication and uptake?

Sources	**What are the problems?**
Personal	
Family	
Social	
Technological	
Economic	
Other-1	
Other-2	

PART D – Aspect of Visualization

404. What are the specific advantages of forecast diagrams? Explain briefly.

a) Meteogram 7-days

Advantages ---

----

b) Meteogram 14-days

Advantages ---

----

c) Seasonal forecast (3-Months)

Advantages ---

PART E: Forecast quality/ (in) accuracy and decision-making

504. How prepared do you feel with the forecast that you received from the weather school?

Not at all *Very much* *I don't know*

1 *2* *3* *4* *5* *0*

Please explain before and after comparison

Before participation	After participation

507. What strategies do you take to address forecast inaccuracy? When do you do that?

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

508. How participatory advisory services helped you for planning your weekly, bi-weekly, monthly and seasonal scale agricultural activities?

Not adequate/poor *Excellent* *I don't know*

1 *2* *3* *4* *5* *0*

Why? ---

----

510. How the forecast information influences decision-making in the following aspects?

Livelihoods activities	How the forecast information influences decision-making
In livestock management	
In aquaculture/fish farming	
Other livelihood activities such as vermin compost production, social affair, buying input, etc.	

<u>PART F: Use of forecast diagram for emergency response and disaster management</u>

601. Did you get an indication of emergency weather events from the forecast diagrams?

YES NO

603. If yes, compare how the forecasts information help you for emergency preparedness activities before the disaster event recently, while in previous years the agricultural and households damages were more.

Recent example: *The cyclone Fani (April 2019) and the cyclone Bulbul (November 9-10, 2019)*

The cyclone Fani (April 2019)

The cyclone Bulbul (November 9-10, 2019)

Other examples from previous (if any)

Thank you for your time!

______________________________ ______________________________

Signature of the investigator **Signature of participant**

Date: ..../................../................

Supplementary Materials 5A

Interview Schedule - Willingness to pay for climate service in Khulna, Bangladesh

Dear Respondent,

Greetings from Wageningen UR. We need your valuable responses about willingness to pay for weather and climate information services for agricultural decision-making. Responses to this questionnaire will be used for research and academic purposes. Your personal data of this interview shall not be used and shared without your written consent. During interviews, you can disagree and withdraw full or part of your responses without giving a reason to the interviewer.

Q: Do you agree for interview x Yes x No **Date: ..../02/2020**

Q: Name of the respondents____

Q: Name of Weather School/Village ____

Q: Gender x Male x Female

Q Age group x 20-29 x 30-30 x 40-49 x 50-59

Q Farming experience x 0-10 x 11-20 x 21-30 x 31-40 x above 40

Q. Marital status x Married x Unmarried x Divorce x Other

Q. Family size ______________________

Q. Education x Primary x Secondary x Graduate x Illiterate x Can sign

Q. Farm size (acres) ______________________

Q. Land ownership status x Personal land x Leased land x Other

Q Access to mobile phone x Yes x No

Q. Personal smartphone x Yes x No

In case of farmers on participatory site

Q. *Imagine that a private company is willing to provide you with similar forecasts that you are currently receiving from the WATERAPPS project. To cover the costs, the company is charging –First Bid------ Taka as subscription fee per month [Office3] from each farmer. Will you accept this offer? If the company is charging …… follow-up-bid …. (if the answer is no to first bid, select lower bid and if the answer is yes to the first bid, select higher bid) will you accept this subscription fee?*

In case of control site

Q. *Imagine that a private company is willing to provide you detailed weather forecasts (5-14 days in advance). This information can be used for changing planting dates, deciding crop acreage, deciding crop varieties, change of land preparation dates, changing fertilizer and pesticide application dates, hiring of labour etc. To cover the costs, the company is charging –First bid------ Taka as subscription fee per month from each farmer. Will you accept this offer? If the company is charging … follow-up-bid … …. (if the answer is no to first bid, select lower bid and if the answer is yes to the first bid, select higher bid) ….. will you accept this subscription fee?*

Signature of the Farmer/কৃষকের স্বাক্ষর ____

Signature of the Interviewer ____

Supplementary Materials 5B

Sample size that participated in the WTP experiment was 59 people for the control group and 52 people from the study site group (111 participants) from whom we collected 110 valid answers. Table A.1 presents the mean family as well as the farm size of the participants of the study, while Table A.2 presents the bid structures that were used in the current study. Table A.3 presents the outcomes of the farmers' willingness to pay for Climate Information Services. Figures A.1 to A.6 present the main sample characteristics for both groups such as gender, age, education, farming experience, use of mobile phones and the percentage of leased land for the year 2020.

Table 5B.1. Main characteristics of the sample size

	family size (people)	**farm size (acres)**
Control site	3.7	3.2
Study site	4.1	3.0

Table 5B.2. Bid structures that were used in the current study

Serial No.	**Initial bid value (BDT)**	**Follow-up lower bid (BDT)**	**Follow-up higher bid (BDT)**
1	20	10	40
2	40	20	80
3	100	50	200

Table 5B.3. Outcomes of the WTP for participatory CIS

YES-YES cases	56	50.9%
YES-NO cases	33	30.0%
NO-YES cases	2	1.8%
NO-NO cases	19	17.3%
Total respondents	**110**	**100%**

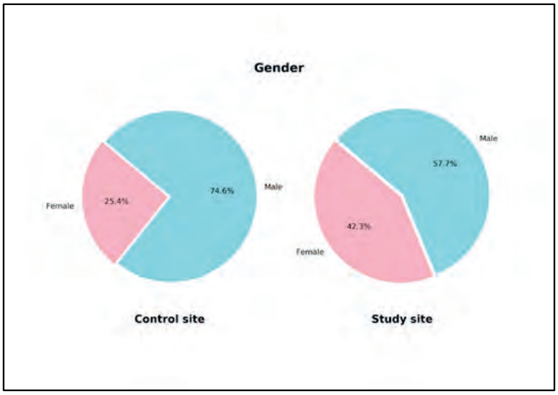


Figure 5B.1. Gender per examined site

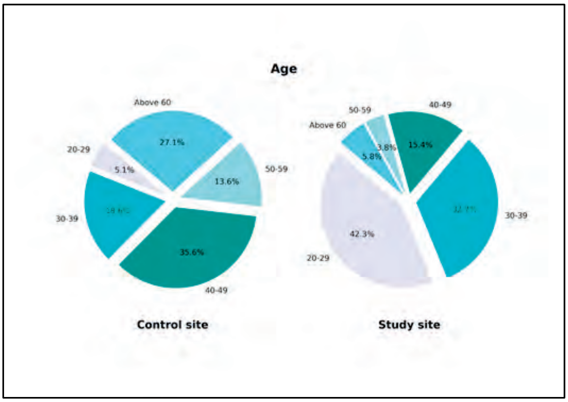


Figure 5B.2. Age per examined site

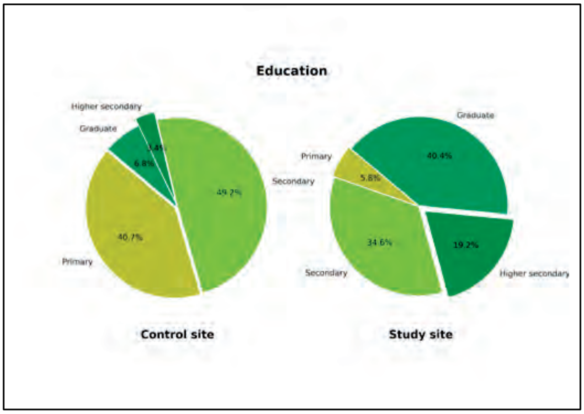


Figure 5B.3. Education per examined site

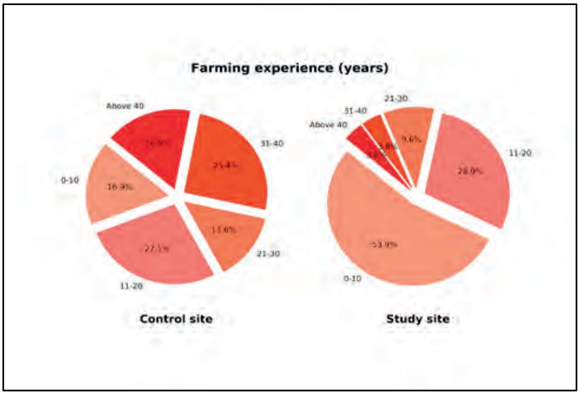


Figure 5B.4. Farming experience (in years) per examined site

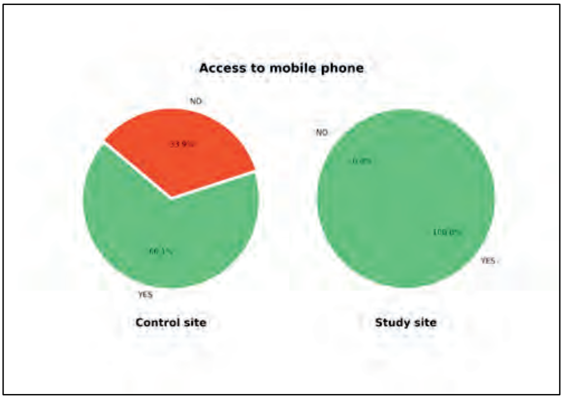


Figure 5B.5. Use of mobile per examined site

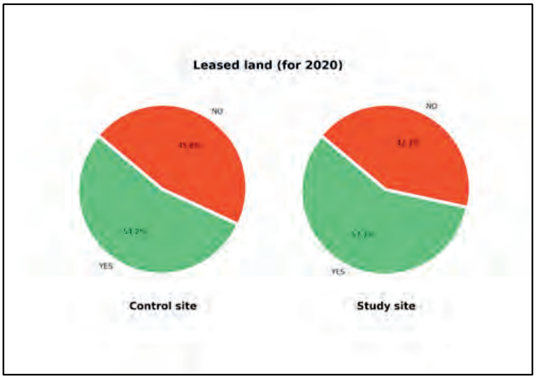


Figure 5B.6. Leased land for 2020 per examined site

Summary

Peri-urban smallholder farmers are very vulnerable to hydroclimatic variability and climate change impacts in the Lower Bengal Delta. They highly depend on seasonal rainfall for agricultural practices and suffer from recurrent hydroclimatic extreme events such as heavy rainfall, drought, cyclones, and storm surge, waterlogging, and salinity intrusion. These extreme events affect agricultural income and livelihood security of, especially poor smallholders. Smallholders account for more than 87 percent of farm households and contribute to about 60% of food national food production. Thus, they play a significant role in the national food security and livelihood of the people of rural Bangladesh.

The development of Climatic Information Services (CIS) has the potential to support the planning and management of agricultural activities with available information and communication technology (ICT). Currently CIS has several limitations in terms of farmers' understanding, timeliness, accessibility, and reliability to local smallholders. The planning of agricultural practices and decision-making (choice of crop, planting, irrigation, harvest, etc.) is largely dependent on the local knowledge and traditional practices of farmers. Farmers require more precise CIS such as daily, weekly, bi-weekly, monthly and seasonal time-scale to manage increased hydroclimatic risks and agricultural practices and decision-making.

The overall objective of this dissertation is to explore smallholders' information needs and co-production of location- and time-specific climate information services with smallholder farmers to support agricultural decision-making in peri-urban Khulna, Bangladesh. To achieve this broad research objective, I answered four research questions regarding (1) farmers' current practices, accessibility, and role of information in agricultural decision-making (2) hydroclimatic information needs assessment of farmers (3) co-producing climate information services with and for farmers, (4) assessment of farmers' willingness to pay for tailored climate information services. A transdisciplinary research approach was followed in each step of the research process to bridge gaps between scientists, service providers, and end-users. This dissertation contributes to the on-going scientific challenge for co-producing CIS to improve decision-making and climate-resilient agricultural practices in the Bengal Delta.

To answer the first research question, I developed a research and data collection framework combining desk research, reconnaissance field visits, focus group discussion (FGD), farmers' interviews, and experts' interviews using a semi-structured questionnaire and checklists. Rupsa and Batiaghata were purposefully selected for this study, agriculturally dominated peri-urban areas in

Khulna, Bangladesh. Findings show that the Department of Agricultural Extension (DAE) lacks access to precise climate information services to support farmers' tactical and strategic decision-making. However, DAE remains aware of sharing of the emergency forecasts delivered by the national hydro-meteorological services. DAE disseminate that information using top-down communication channels such as radio, television, and local extension department. Therefore, forecasts often come late or with a short-lead time (1-3 days or less). Farmers remain dissatisfied and often claim that and BMD, BWDB, and DAE fail to understand farmers' information needs and advisory services in a timely and actionable fashion. The local service providers and end-users have no involvement in designing and delivering CIS at the local levels. ICT-led service is still very limited in use and attached a little value based on usage that needs capacity training and service co-development with the local extension agencies and end-users farmers. I sketched 14 major climate-sensitive farming decisions with farmers. I conclude that there is a potential for developing climate information services in the study area addressing farmers' needs and capacity building. A bottom-up co-production approach should be followed for service development with an ICT-led users' platform.

To answer the second research question, I develop and apply a five-step farmers' engagement process - user platform, user engagement, baseline assessment, capacity building, end-line assessment. The farmers' engagement process helps to understand the weather and water-related information needs of smallholders in the Bengal Delta. I compared baseline, and end-line information needs assessment combining field visits, participatory meetings, and personal interviews with farmers. During the baseline needs assessment, farmers faced difficulty expressing their specific information needs. However, after capacity building and frequent interaction, experimental farmers noticed changes in information needs, forecast lead-time, and parameters of interest. Farmers emphasized rainfall, cyclones, storm surge, hailstorm, fog, drought, and extreme rainfall are their foremost information needs. Besides, farmers expressed water-related information needs such as soil and water salinity for precise agricultural decisions. Smallholders in the Lower Bengal Delta have a higher preference for weekly and biweekly forecasts. Indeed, smallholders perceive the usefulness of the seasonal forecast with a 1-month time-scale ahead of a crop season. I conclude that information needs assessment is not a single-step process. Capacity building and iterative interactions at farmer field school (FFS) have enabled farmers to express their information needs more explicitly.

To answer the third question, therefore, I applied the FFS approach for communicating visual diagrams of 7-day, 14-day, and seasonal (3-month) forecasts during face-to-face meetings using printed paper, and a smartphone app. A total of 58 (n=32+26) experimental farmers were involved in two field schools combining male and female participants. I develop a new framework for the co-production of CIS through forecast visualization and communication. I conducted primary meetings, weekly interactions and monitoring, and final evaluation through personal interviews and group meetings using semi-structured checklists and questionnaires.

Smallholders gained better understanding and interpretation skills of visual forecast diagrams followed by iterative interactions and training. I observed that after receiving training, the visual forecast diagrams were used by all farmers. Farmers weekly interactions built trust on forecast information and hands-on experience of applying forecasts in decision-making. The ICT platforms have the potential for effective communication and dissemination of information and advisory services timely and widely among smallholders. Farmers reported an increased uptake of the forecast information due to improved capacity, information quality (accuracy) and services, time-specificity, flexibility to access information, forecast visualization, and communication. Farmers highly valued feedback collection in weekly meetings as it offered a comparison with local observation. I observed that farmers frequently accessed forecasts from field schools. This significantly reduced their dependence on traditional platforms such as peers, radio, television, and newspaper. I conclude that co-production effort through forecast visualization and communication modes has resulted in broader sharing, dissemination, and uptake of the scientific forecast for smallholders' climate-sensitive decision-making. I also noticed a behavioral change of smallholders due to training, interactions, and the participatory co-production process.

To answer the fourth research question, a double-bounded dichotomous contingent valuation method was employed to estimate the farmers' willingness to pay (WTP) for participatory climate information services. This study provides an understanding of WTP for future co-production of climate services in the Bengal Delta. The WTP of the experimental farmers was compared with a control farmers' group. The experimental farmers received training and participatory interaction on CIS, where the control farmers' group had no prior training and participatory interactions. The result shows that 90% of the study site farmers are willing to pay for tailored climate services. The provisioned WTP value for CIS is the main driving factor, followed by whether the farmers have received training and capacity building on weather and climate-related phenomena. At the control site, 75% of farmers indicated that they are willing to invest in location-specific tailored weather and climate information services for agricultural practices and decision-making. Overall, the mean willingness to pay for CIS when using only treated as an explanatory variable (model 1) is 95.82*Tk* (1.00€) per month or 1,149.84*Tk* (12.05€) per year. Several explanatory variables besides treatment such as gender, age, education, farm, and

family size, influence farmers' willingness to invest 95.35*Tk* (1.00€) per month or 1,144.20*Tk* (12.00€) per year. I conclude that tailored CIS has a business potential for agricultural development and food production in the Bengal Delta.

Finally, this dissertation provides empirical evidence for climate services co-production addressing the scientific, socio-economic, and technical challenges. A participatory co-production process has established a new farmers' cantered platform, *'Farmers Weather Club'* for climate-smart agricultural practices in the Bengal Delta. This dissertation recommends bridging gaps between scientists, sectoral experts, intermediaries, and end-users at farmer field schools combining capacity building, participatory engagements, and ICT support. Co-production at field schools will improve broader sharing, uptake, and climate-resilient decision-making in complex socio-economic and environmental settings of the smallholders and sustainability.

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Mr. Uthpal Kumar was born on 26th December 1981 in Chapainawabganj, Bangladesh. He started as a Ph.D. researcher at Water Systems and Global Change Group (WSG) of Wageningen University and Research in the Netherlands in January 2017. Mr. Kumar holds a Bachelor of Science Degree in Environmental Science (2005) from Khulna University (KU), Bangladesh, and a Master of Science Degree in Water Resources Development (2008) from Bangladesh University of Engineering and Technology (BUET). Since then he has had research-based positions in several projects at Unnayan Onneshan, Institute of Water and Flood Management (IWFM, BUET), and Caritas Development Institute. The research and academic interest of Mr. Kumar are climate services, integrated water resources management, vulnerability assessment, and Rural-Urban DRR. Currently, Mr. Kumar is working as a postdoctoral researcher for the KU-WSG collaborative project 'WSGWATERAPPscale - upscaling WATERAPPS information services for sustainable food production in peri-urban delta areas in Bangladesh'.

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Work experience

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11/2013-12/2016	Research Fellow - Caritas Development Institute, Dhaka, Bangladesh
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Recent publications

Kumar, U., Werners, S., Paparrizos, S., Datta, D.K., and Ludwig, F. (2021). Co-production Hydroclimatic Information Services with Farmers in the Lower Bengal Delta: how forecasts visualization and modes of communication support farmers' decision-making. Climate Risk Management (under review).

Paparrizos, S., **Kumar, U.,** Babu T. S. A., and Ludwig, F. (2020). Are farmers willing to pay for participatory climate information services? Insights from a case study in the peri-urban area of Khulna, Bangladesh. Climate Services (under review)

Kumar, U., Werners, S., Paparrizos, S., Datta, D.K., and Ludwig, F. (2020). Hydroclimatic Information Needs of Smallholder Farmers in the Lower Bengal Delta, Bangladesh. Atmosphere, 2020, 11(9), 1009. https://doi.org/10.3390/atmos11091009

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Ashraf, S., **Kumar, U**., Roy, S. and Datta, D.K., 2020. Virtual Water Information for Water and Food Security in Peri-Urban Khulna: Present Status and Future Requirement. In Water, Flood Management and Water Security Under a Changing Climate (pp. 331-341). Springer, Cham. https://doi.org/10.1007/978-3-030-47786-8_23

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The SENSE Research School declares that Uthpal Kumar has successfully fulfilled all requirements of the educational PhD programme of SENSE with a work load of 49.9 EC, including the following activities:

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- GIS in practice, PE&RC graduate school (2018)
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- *Climate Services for Sustainable Agricultural Practices in the Lower Ganges Delta Bangladesh*. 4th International Conference on Sustainable Development, 18-19 February 2020, United International University, Dhaka, Bangladesh

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