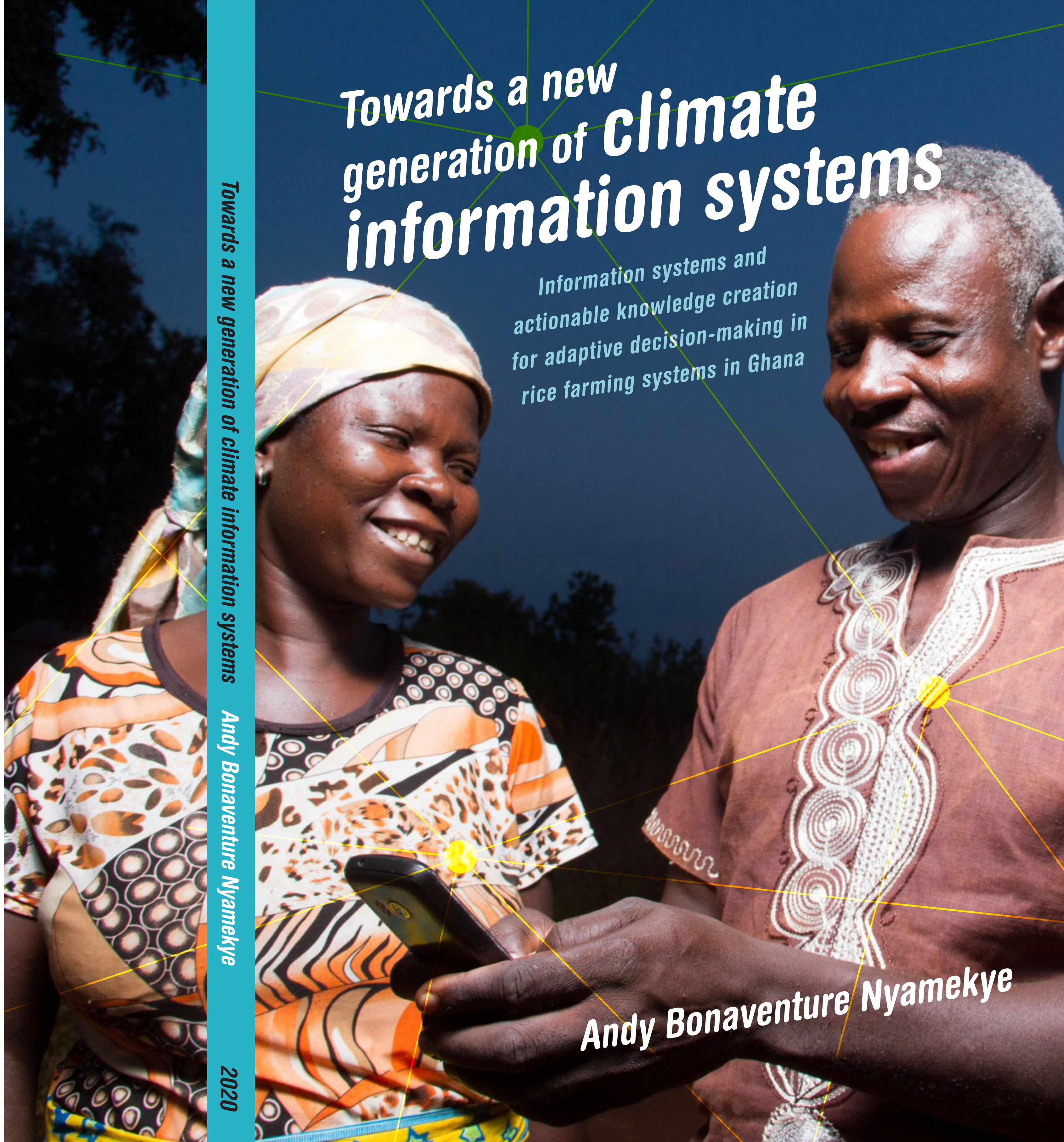

Towards a new generation of climate information systems

Information systems and actionable knowledge creation for adaptive decision-making in rice farming systems in Ghana

Andy Bonaventure Nyamekye

Towards a new generation of climate information systems Andy Bonaventure Nyamekye 2020

Propositions

1. To adapt is to be certain about uncertainty.

   (this thesis)

2. Information systems are as much social and technological constructs.

   (this thesis)

3. Science should be ‘with’ instead of ‘for’ society.

4. Doing interdisciplinary research is analogous to building the ‘Tower of Babel’.

5. Global challenges must be addressed by exploring our inactions equally as our actions.

6. Our footprints in life define us better than our shadows.

Propositions belonging to the thesis, entitled

Towards A New Generation of Climate Information Systems: Information Systems and Actionable Knowledge Creation for Adaptive Decision-making in Rice Farming Systems in Ghana

Andy Bonaventure Nyamekye

Wageningen, 24 August 2020

Towards A New Generation of Climate Information Systems

Information Systems and Actionable Knowledge Creation for Adaptive Decision-Making in Rice Farming Systems in Ghana

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Thesis committee

Promotors
Prof. Dr ARPJ (Art) Dewulf
Personal chair, Public Administration and Policy Group Wageningen University & Research

Prof. Dr C.J.A.M. Termeer
Professor of Public Administration and Policy
Wageningen University & Research

Co-promotor
Dr . EJJ (Erik) van Slobbe
Researcher and Teacher, Water Systems and Global Change Group
Wageningen University & Research

Other members
Prof. Dr C (Cees) Leeuwis, Wageningen University & Research
Prof. Dr S.V (Sander) Meijerink- Radboud University, Nijmegen
Prof. Dr Gordana Kranjac-Berisalvejic, University for Development Studies, Tamale, Ghana
Dr Annemarie Groot, Wageningen University & Research

This research was conducted under the auspices of the Graduate School of Social Sciences (WASS)

Towards A New Generation of Climate Information Systems

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Thesis
submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus,
Prof. Dr A.P.J. Mol,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Monday 24 August 2020
at 11 a.m. in the Aula.

Andy Bonaventure Nyamekye

Towards A New Generation of Climate Information Systems: Information Systems and Actionable Knowledge Creation for Adaptive Decision-Making in Rice Farming Systems in Ghana
294 pages

PhD thesis, Wageningen University, Wageningen, the Netherlands (2020)
With references, with summary in English
ISBN: 978-94-6395-409-9
DOI: https://doi.org/10.18174/522206

Dedicated to my mother

Acknowledgement

Indeed the value of life is in the footprints we leave behind. My PhD journey has been successful courtesy many who in various capacities have guided, guarded and supported me and for which I am eternally thankful. To these, I am deeply indebted to now and beyond as every step of my journey in life will be a reflection of their purposeful impact.

First I wish to thank the leadership of the EVOCA programme and funders for the opportunity to be part of such a diverse PhD programme focusing on topical issues relevant for my career and path. My appreciation goes especially to Professor Cees Leeuwis, Vera Mentzel, Inge Ruisch, Mirjam Cevat for their incessant support in ensuring resources were available throughout my study period.

Secondly, my deepest gratitude and indebtedness goes to my supervisory team for their remarkable support. To my first promotor, Professor Art Dewulf, I will forever remain thankful for your availability to shepherd the young Ghanaian seeking to become a scholar. To this moment, I see myself chartering a scientific path for which your footprints have showed the way. The advice, admonishment and social support have been my source of strength. My appreciation also goes to my second promotor, Professor Katrien Termeer for the guidance throughout my PhD study. I am thankful for the several moments of encouragement and feedback on my thesis which has led to this end. I am thankful to my co-promotor Dr. Erik Van Slobbe for the tremendous support throughout my PhD research. Your timely feedback and inputs over the period also accounted for my progress and completion. I also acknowledge the support of the rest of the water case supervisory team-Professor Fulco Ludwig, Dr. Saskia Werners and Dr. Robert Biesbroek. Your collaboration brought us to this end.

To my fellow 'EVOCANS' I say this has been the best family ever. First to my research partner Emmanuel Nyadzi, I sincerely appreciate the healthy collaboration we shared over this journey. What more could I have asked for! To my colleagues Elias Dantew Assefa, Christopher Agyekumhene, Shiferaw Tafesse Gobena, Faith Mutavi, Nyamwaya Munthali, Marilyn Murindahabi, Mariette McCampbell, Domina Asingizwe and Richard Chepkwony, thanks for being a wonderful team. To our greatest anchor, Dr. Katarzyna Cieslik, you were ready to listen and to stir up the confidence and enthusiasm we needed in this research programme.

I am thankful to the research and teaching staff at the Public Administration and Policy Group; Dr. Otto Hospes, Dr. Tamara Metze, Dr. Jeroen Candel, Dr. Agatha Siwale, Dr. Robert Biesbroek and Dr. Sylvia Karlsson-Vinkhuyzen. Your periods of socialization and academic engagements have shaped me. To postdocs and my colleague PhDs; Dr. Sumit Vij, Dr. Giulia Bazzan, Dr. Elaine Teixeira Rabello, Wieke Pot, Daniel Wiegant, Yannick Buitenhuis, Brenda Namugumya, Rebecca Sarku, Junnikkala Maarit, Efrat Gommeh, Ellen Brauers, Louise Cavalcante de Souza Cabral, Eduardo Padilla, Olga Schagen, Christel van Eck, Jan Starke, Lara Sibbing and Ahmad Dermawan, thank you for being wonderful teammates. Special thanks goes to our office manager, Maarit Junnikkala, for always opening your doors to me. My sincere thanks also goes to staff and PhDs at the Water Systems and Global Change Group.

I am extremely grateful to Cornie Quist, Els Upperman and the family for opening their doors to me especially during the housing crisis. Thank you for the love, care and guidance over the past months.

I also acknowledge the bigger family of Ghanaians in Wageningen. Thanks for your friendship and social support.

To my very close brothers in academia, Dr. Emmanuel Frimpong Boamah and Dr. Thomas Yeboah, thanks for your support and advice as we journey along.

My heartfelt gratitude also goes to my second family-Dr. Ronald Adamtey, Mrs. Dorothy Adamtey, Kirsten Adamtey, Tracy Adamtey, Arnold Adamtey and the rest of the family. Such a blessing the family has been to me.

In all these, my family has been pivotal with love and support. To my mum, Gifty Bentil, this is for you. To my dad-Bonaventure Nyamekye, my sister-Elsie Nyamekye and brother-Eric Frimpong Agyepong, your well wishes have yielded fruits.

Abstract

With the bane of climate variability and its consequences for water availability in rice farming systems, farmers have relied heavily on climate information systems for meteorological information to help manage uncertainties and create actionable knowledge for decision-making. However, the limited impact of existing information systems calls for further research on what could be done differently to improve information gathering and synthesis, the cross-fertilisation of knowledge, and the elimination of social and technical barriers in these systems. This dissertation sets out to study existing information systems, how these contribute to actionable knowledge creation in rice farming systems, what adaptive decisions farmers take in managing uncertainties, and how best to restructure climate information systems for impact.

Because of the multi-faceted nature of the problem, the study adopts an interdisciplinary research approach and provides evidential justifications using a case study in Ghana. Generally, the dissertation draws on qualitative research methods such as focus group discussions, interviews, workshops, and observations, with data analysed by content and theme. The study proposes a new framework for climate information systems and adds to the further conceptualisation of actionable knowledge and adaptive decision-making in rice farming systems. It shows that both indigenous and scientific knowledge should be considered in establishing the salience, credibility, and legitimacy of knowledge created through information systems in rice farming systems. It also contributes strongly to the conceptualisation of adaptive decision-making by drawing on uncertainties and logics of decision-making.

The scientific and societal relevance of this study is grounded not only in its contribution to scientific debates on information systems, actionable knowledge, and adaptive decision-making, but also in its action-oriented approach contributing to practical designs of climate information systems that promote collaborative and participatory processes to formulate information needs and what best could be actionable in rice farming systems.

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Chapter 1

General Introduction

1.1 Background and problem definition

Sub-Saharan Africa is arguably the region most vulnerable to climate variability, as evidenced by higher temperatures, low precipitation, flooding, and drought resulting in severe impacts on food production exacerbated by low adaptive capacities (Hendrix & Glaser, 2007; Kotir, 2011). In Ghana, recorded temperatures rose about 1^{o} C over the last 40 years of the twentieth century, with high temperatures mostly in the north of the country and dire consequences for agricultural productivity (Akudugu, Dittoh, & Mahama, 2012; Fosu-Mensah, Vlek, & MacCarthy, 2012; Abdul-Razak & Kruse, 2017). In Kumbungu District in Northern Ghana, rice farmers are faced with an uncertain future, with a lack of security about future seasonal and weather conditions increasing the level of risks that they have to surmount.

Government interventions such as irrigation infrastructure have proved inadequate. In a context where farmer population thresholds merit such interventions, poor maintenance practices, financial constraints, and weak governance structures have hampered their multiplier effect when they are introduced into communities (Bacho & Bonye, 2006). The construction of irrigation dams was expected to improve water management through the storage and discharge of water for irrigation purposes. The Bontanga Irrigation Scheme is one of numerous government interventions to support food production in the northern part of Ghana. The scheme serves communities within Kumbungu District, with farmers accessing water for irrigation purposes. However, the majority of households still practice rainfed farming given the limited land area for cultivation under irrigation, amongst other reasons (Alhassan, Loomis, Frasier, Davies, & Andales, 2013; Kudadze, Imoru, & Adzawla, 2019; Zakaria, Abujaja, Adam, Nabila, & Mohammed, 2013). Of these, rice farmers, given the crop's copious water requirement, are at a high risk of crop failure, especially in rainfed farming systems. This requires farmers to adapt their practices by taking decisions towards reducing vulnerabilities and limiting probabilities of crop failure.

Effectively, farmers require forecasts of rainfall amount, rainfall distribution, temperature, humidity, and wind speed to be made available through information systems. These are comprised of public (e.g. Ghana

Meteorological Agency) and private (e.g. ESOKO, Farm radio, Farmer line) social or technological systems enabling the collection, processing, and dissemination of information to support decision-making (Laudon, 2012; Rainer, Cegielski, Splettstoesser-Hogeterp, & Sanchez-Rodriguez, 2013). Although the provision of seasonal and weather information is expected to reduce risks faced by farmers, studies in Ghana have pointed to their limited impact at farm level because of misconceptions about information needs, untimeliness, non-relevance, and limited uptake and use in decision-making (Agyekumhene et al., 2018; Aker, 2011; Alemna & Sam, 2006; Annor-Frempong, Kwarteng, Agunga, & Zinnah, 2006; Munthali et al., 2018). Also, information disseminated is packaged in machine-readable formats, making it difficult for farmers to interpret, given their low literacy levels. Farmers also resort to *de facto* indigenous knowledge using indicators such as the movement of birds, wind direction, and behaviour of farm animals. However, the reliability of indigenous indicators has been questioned, as changes in natural and environmental conditions make them less reliable than before. Fundamental to the challenge is the underlying factor of participation and collaborative framing of information through co-production, which seems to be lacking in the way in which current information systems operate. There is also the question of scale, whereby information systems are unable to provide geographically segregated meteorological information at farm or community level. In effect, information provision and how that transforms into actionable knowledge applicable to farmer decision-making in efforts to adapt to changing social and environmental conditions must be studied to improve the transformational power of meteorological information (Partey et al., 2018; Mabe, Nketiah, & Darko, 2014).

In current literature on how to bridge the information provision and uptake gap through a collaboration of scientists and citizens, a new generation of environmental virtual observatories (EVOs), including information systems, have been highlighted as presenting such opportunities. Karpouzoglou et al. (2016a, p. 1) define EVOs as 'a suite of information gathering, processing and dissemination technologies (infrastructure, tools and software) supported by World Wide Web that can enable cross-fertilisation of different sources of knowledge on shared virtual platforms'. Thus, the thrust of EVOs is the collation, processing, and synthesis of knowledge to make it actionable using technologies and support from the internet (Vitolo, Elkhatib, Reusser, Macleod, & Buytaert, 2015; Zacharias et al., 2011). However, EVO as a concept is still evolving, with the need to investigate how so-called second generation EVOs, including information systems, could help address the information–knowledge–decision-making interrelationship in social and ecological systems in order to manage complex problems.

This dissertation is embedded in the EVOCA programme led by Wageningen University and Research and its partners, which has the goal of exploring how EVOs could be leveraged to transform the development landscape in rural Africa. The programme has the theme ‘Responsible life-science innovations for development in the digital age’ and addresses the overall question: How can life-science knowledge, digital technologies, and responsible innovation concepts be leveraged in development contexts to build inclusive virtual platforms for environmental information that enable connective action to address development challenges in crop, water, health, and wildlife management?

In line with this, this dissertation focusing on rice farming systems in Ghana set out first with the goal of inquiring into how existing information systems contribute to actionable knowledge creation for adaptive decision-making and second to contribute to the debate on how climate information systems can be better framed to improve cross-fertilisation of knowledge for decision-making amidst water insecurities in rice farming systems in Ghana. More specifically, the dissertation focuses not only on design questions but also on how forecast information translates into actionable knowledge and uptake in decision-making. The dissertation addresses the overall question: How do existing information systems contribute to actionable knowledge creation for decision-making in rice farming systems and what does this mean for the establishment of a new generation of climate information systems?

1.2 Climate information systems and adaptive governance in farming systems

Adaptive governance has emerged in the last decade as a lens of both theory and practice (Amelia, Paturusi, & Merit, 2019; Bedi, 2019; Brunner & Lynch, 2013; Sharma-Wallace, Velarde, & Wreford, 2018) for managing complex environmental problems consequent to the recognition of failures of previous management regimes. In farming systems specifically, the increasing pressure from dynamic environmental, political, social, and economic stressors has necessitated a shift from traditional government to a new form of governance that is adaptive to changing conditions (Pereira & Ruysenaar, 2012). Central to adapting to such complex changes are information, knowledge, and learning shaped by practices along the pathway of change, involving interaction between actors at different levels of governance within food systems. Significantly, actionable knowledge for the adaptive governance of food systems could be improved through the use of emerging platform technologies in the form of information systems where information is transformed into knowledge through informational processes, institutions, and practices (Cameron, Somachandra, Curry, Jenner, & Hobbs, 2016; Evans, Terhorst, & Kang, 2017).

One of the key propositions regarding technology and adaptive governance that has gained traction is the subject of EVOs. Virtual observatories are not a new subject in our society. For example, the emergence of virtual observatories in the early 2000s in Europe and the Americas in astronomical surveys led to the formation of the International Virtual Observatory Alliance (IVOA) in 2002 (Hanisch, 2014). However, global environmental change has precipitated experimentation with virtual observatories at different temporal scales. In the context of current global challenges, discussions have shifted to how scientists and citizens can collaborate in managing complex problems such as those experienced in farming systems (Gouveia, Fonseca, Camara, & Ferreira, 2004; Savan, Morgan, & Gore, 2003).

Karpouzoglou et al. (2016a) add to this discussion with a further conceptualisation of EVOs. These authors indicate that EVOs take the form of environmental sensor networks, knowledge and data portals, or environmental data visualisation and monitoring platforms. They highlight the dominance of scientists in these systems, engaged mostly in environmental modelling to maximise the use of new technologies in the characterisation of natural systems. The authors conceptualise the aforementioned systems as first generation EVOs. For them, the emphasis here is on scientific information collation and processing for a scientific audience. However, they create a second category of EVOs, which they classify as second generation EVOs (see Figure 1.1). They indicate that these EVOs concentrate on co-creation of knowledge via interaction between multiple stakeholders such as community-based environmental monitoring systems. Thus, second generation EVOs lean towards user-centred designs and networks (Athanasiadis & Mitkas, 2004; Beven, Buytaert, & Smith, 2012;Cieslik et al., 2018; Kimmins, Rempel, Welham, Seely, & Van Rees, 2007; Mancuso & Bustaffa, 2006; Stepenuck & Green, 2015; Zulkafli et al., 2017).

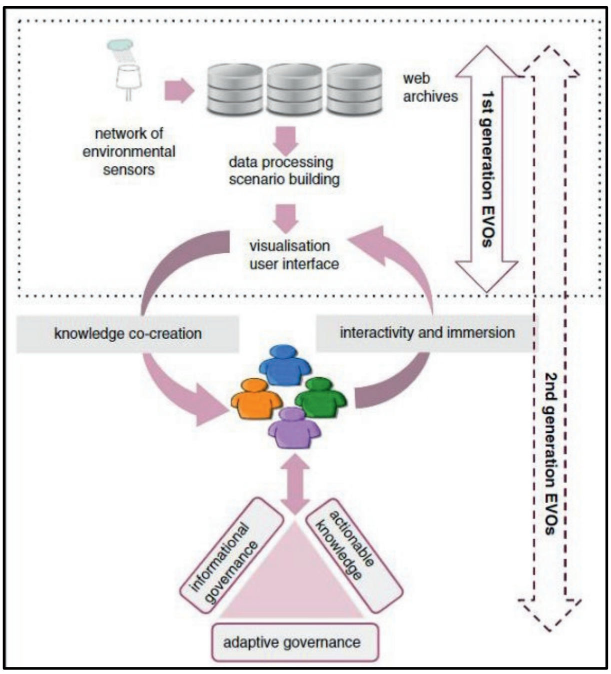


Figure 1.1: First and second generation EVOs

Increasingly, the interaction between stakeholders enabled by second generation EVOs, including information systems, is expected to improve the adaptive governance of social-ecological systems (Folke, Hahn, Olsson, & Norberg, 2005; Pereira & Ruysenaar, 2012; Karpouzoglou et al., 2016). The processes and mechanisms that underlie the approach have been tested in multiple contexts, informing a shift in framing to comprise not only management, but also social conditions (Armitage, Berkes, & Doubleday, 2010; Folke, 2007; Walker, Hollin, Carpenter, & Kinzig, 2004). The thrust, according to Folke et al. (2005), is that, following abrupt changes, adaptive governance systems often self-organise and hence crises could be opportunities to transform into a more desired state. To this end, second generation EVOs can enable stakeholder collaborations and joint framing of crises to respond and adjust when needed.

In the context of farming systems, farmers and other stakeholders can collaborate in dealing with social and ecological shifts, with information systems such as observatories enabling self-organising through an information lens (Fridman & Lenters, 2013; Hipsey et al., 2015). Nevertheless, research must provide scientific evidence in farming systems of how farmers adapt through decision-making to deal with crises such as climate change and how information systems contribute to this, as shown in Figure 1.2 (Dutton, 2002; Vaughan & Dessai, 2014; Visbeck, 2008). Wilkinson et al. (2013) refer to a growing recognition that the involvement of local communities in land and water management decisions has a multiplier effect in the form of economic, social, and environmental benefits. They indicate that cloud-based technologies such as EVOs can facilitate the process of information exchange. The authors elaborate on how an Environmental Virtual Observatory Pilot project (EVOp) was designed by the UK Natural Environment Research Council as part of a proof of concept. The vision for setting up the EVO was to make environmental data visible and accessible to a range of potential users; to provide tools for data integration, greater access to knowledge; and to develop new added-value knowledge. However, there is a need to address urgent research gaps in first generation EVOs and what these gaps present for second generation EVOs, ranging from design to application. For example, what technologies should be considered? How should data be packaged as applicable information? How do we cross-fertilise knowledge?

Mol (2006), borrowing from Castells (1996), points to a new informational mode of environmental governance to which he refers as informational governance. In differentiating informational governance from conventional modes of environmental governance, the author opines that informational governance refers to ‘the idea that information (and informational processes, technologies, institutions, and resources linked to it) is fundamentally restructuring processes, institutions, and practices of environmental governance’ (Mol, 2006, p. 5). Whereas conventional environmental governance relies on authoritative resources and the power of the state, in informational governance, information becomes a resource with transformative powers for multiple stakeholders and networks. Understanding these transformative powers dovetails into establishing how stakeholders make sense of information received.

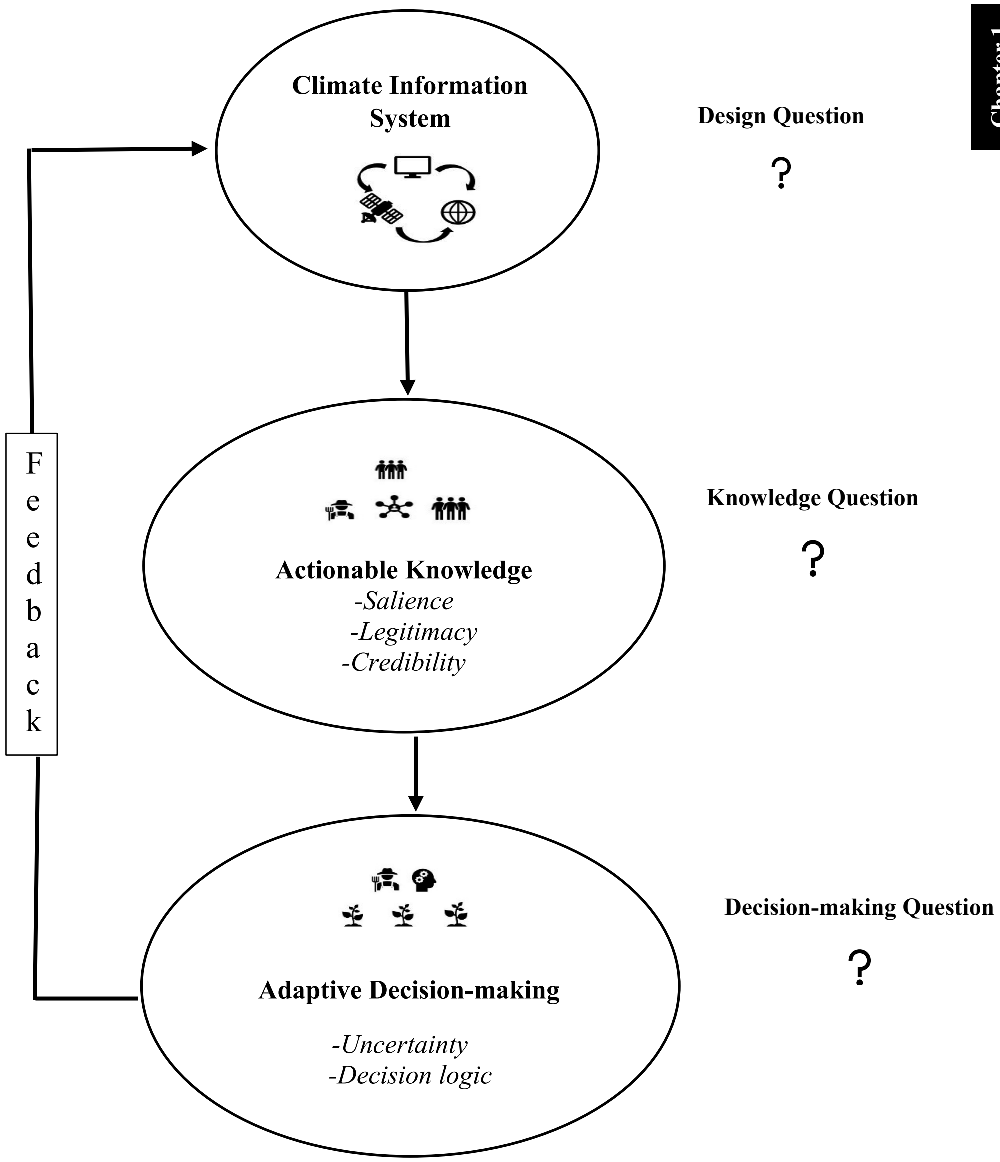


Figure 1.2: Climate information systems and adaptive governance in farming systems

1.3 Conceptualising actionable knowledge and adaptive decision-making in rice farming systems

1.3.1 Conceptualising actionable knowledge

In social-ecological systems, information is expected to contribute to new applicable knowledge in dealing with change. The term, actionable knowledge, has been used in multiple contexts to signify knowledge that drives people to act. Cross and Sproull (2004) define actionable knowledge as knowledge that leads to immediate progress on a current assignment or project. Shipper et al. (2007), borrowing from Cummings and Jones (2003), define actionable knowledge as knowledge that meets scientific rigour and allows individuals to make informed choices about important practical problems and to implement solutions to them effectively. Geertsema et al. (2016) use the term to depict knowledge that specifically supports stakeholder decision-making and consequent actions. Thus, there is an emphasis on actionable knowledge being produced from an interactional process and a reference to ultimate use in decision-making (Dewulf, Craps, Bouwen, Abril, & Zhingri, 2005; Ingelgård, Roth, Styhre, & Shani, 2002; Meinke et al., 2006; Nana, Asuming-Brempong, & Nantui, 2013).

As indicated, actionable knowledge has been interpreted and measured differently in multiple contexts. In the domains of information and knowledge research, reference is made not only to scientific knowledge but also to indigenous knowledge systems (Kirchhoff, Lemos, & Dessai, 2013; Koocheki, 2003; Warren & Cashman, 1988). In the context of this thesis, I focus on actionable knowledge creation in information systems in rice farming. The adoption of ICT-driven technologies has increased in food systems in developing countries such as Ghana, with interventions from both the private and the public sector. Interventions have leveraged the high penetration of mobile phone technology in both urban and rural parts of the country. However, the adoption of technology for information provision has not necessarily translated into gains in the form of new knowledge, especially at local scales for use by farmers (Aker, 2011; Alemna & Sam, 2006; Conley & Udry, 2001).

Borrowing from the work of Cash et al. (2003), I argue that the interactional process of knowledge creation from information involves an interplay of the factors of salience, legitimacy, and credibility within rice farming systems (see Figure 1.2). The authors refer to salience as scientific information being made responsive and context sensitive to decision-makers' needs; credibility as information being accurate, of high quality, and scientifically valid; and legitimacy as the context of producing information through an open and unbiased process.

However, given the prevalence of multiple knowledge systems in rice farming systems in Northern Ghana, it also needs to be established how not only scientific but also indigenous knowledge comes into play in actionable knowledge creation, although Cash et al. (2003) focus on scientific knowledge. What is actionable could also be context specific, as confirmed by Dewulf et al. (2005), whereby knowledge is embedded in communities of practice following an interwoven process involving both explicit and tacit knowledge. I estimate how EVOs can contribute to actionable knowledge creation by drawing on how current information systems in rice farming systems enable actionable knowledge creation. I define actionable knowledge as indigenous and scientific knowledge that is locally relevant, trustworthy, and produced in a fair, transparent way. I define salience as locally relevant, timely, and relatable scientific and indigenous knowledge; credibility as knowledge that is trustworthy and can be based on scientific evidence or trust in the experience (indigenous knowledge) of fellow farmers; and legitimacy as scientific and indigenous knowledge produced in a fair, balanced, and transparent way.

1.3.2 Conceptualising adaptive decision-making

Decision-making in farming systems is shrouded in uncertainty about numerous conditions, including seasonal and weather variability. In the trio-chord of information provision, knowledge creation, and decision-making, reference is made to the complexities at the point of decision-making that can be attributable to the lack of complete information of future events and divergent frames in other contexts (Clements, Haggar, Quezada, & Torres, 2011; Howden et al., 2007; Meinke & Stone, 2005; Risbey, Kandlikar, Dowlatabadi, & Graetz, 1999). One key concept is that of adaptive decision-making. Decision-making theories have been characterised by a shift in perspective from structuralist to constructivist views with reference to uncertainty, and hence decision-makers can be rational only to the degree of choice framing underpinned by information and knowledge of events (Gigerenzer & Selten, 2002; Simon, 1972). The adaptive decision-maker is ‘methodological, systematic, independent and unimpulsive throughout the decision-making’ (Phillips, 1997, p. 276), but this still might not result in utility maximisation due to ‘ignorance, obtuseness, or deviousness’ (March, 1978, p. 598), and hence decision-makers are boundedly rational, as argued by Simon (1972).

The dissertation adds to the discussion with a focus on two logics of decision-making (the logic of consequentiality and the logic of appropriateness) propounded in rational theories pioneered by March and Olsen (1976). The logic of consequentiality connotes the idea that decision-makers have a knowledge of alternatives available and consequences or outcomes of alternatives, and follow a rule whereby they select one alternative on the basis of its consequences and act accordingly to maximise their benefits (Edmondson & Moingeon, 1998; March & Olsen, 1976; Nalbandov, 2009; Ostrom, 1991). Contrastingly, the logic of appropriateness perceives human action and decision-making as driven by rules of appropriate behaviour, organised into institutions. The urge is to follow what is socially defined as true or right in spite of consequences and expected utility. Key questions posed by the decision-maker include: What are the decision options? What are my preferences? What are the consequences of the different options for my preferences? Which option has the most favourable consequence?

I conceptualise farmer decision-making with reference to adaptive decision-making whilst drawing on both logics indicated above. Adaptive decision-making refers to non-standard decision-making in response to change (Hogan, Berry, Ng, & Bode, 2011; Lal, Lim-Applegate, & Scoccimarro, 2002). I also draw on two forms of uncertainty in decision-making: substantive and institutional uncertainty. Substantive uncertainty has to do with gaps and conflicting understandings in knowledge, with the consequence that there is limited understanding of the nature of a problem (Head, 2014). Institutional uncertainty connotes uncertainty about the rules of the game in decision-making and how they transform (Koppenjan & Klijn, 2004). I argue for a relationship between decision logics and forms of uncertainty faced by farmers and adaptive decision-making in rice farming systems, as shown in Figure 1.2. Adaptive decision-making by farmers could be underpinned by either of the logics (Stuart, Schewe, & McDermott, 2014; Willock et al., 1999; Wilson, Hooker, Tucker, LeJeune, & Doohan, 2009).

1.4 Research questions

From the problem analysis in section 1.1, I pose the key question: How do existing information systems contribute to actionable knowledge creation for decision-making in rice farming systems and what does this mean for the establishment of a new generation of climate information systems?

In pursuance of the above, I investigate three key research questions:

RQ 1: *What principles could guide the design and operationalisation of climate information systems in rice farming systems in Northern Ghana?*

As an entry point, it is essential to reflect on key conceptualisations that exist in the literature on how climate information systems could be designed and operationalised. This involves combining both empirical evidence and theoretical dispositions to ensure the leverage of opportunities and limitations, be they technical or social. To this end, the question also leads to a possible framework for a climate information system that could be operationalised in Ghana.

RQ 2: *How do governance arrangements influence farmer adaptive decision-making given uncertainty and information needs?*

This question seeks to establish empirically the rules, processes, and structures that exist in rice farming systems and how these inform adaptive decisions taken by farmers at farm level. Conceptually, addressing the question informs how change within these rules contributes to interpreting the different forms of uncertainties and farmers' adaptive decisions. It involves establishing the decision-making logics that serve to underpin farmers' decisions in adapting to change in the presence of uncertainties. The question also attempts to address farmer information needs in a new breed of climate information systems.

RQ 3: *How do existing information systems enable actionable knowledge creation and what information could improve decision-making in rice farming systems?*

As a functional climate information system is anticipated to contribute to actionable knowledge creation, this research question explores existing information systems and the degree to which they enable actionable knowledge creation and what second generation climate information systems could do differently. The question also contributes to the conceptualisation of actionable knowledge by inquiring into the components of knowledge that drive action in rice farming systems. Furthermore, through the lens of second generation information systems, the study aims to investigate what a functional climate information system could do differently to improve actionable knowledge creation and farmer adaptive decision-making.

1.5 Methodological approach

Interdisciplinary studies involving both social and natural sciences in investigating current global challenges have become necessary because of the complex nature of today's problems (Diaz, Aguirre, & Rodriguez, 2004). Tobi and Kampen (2018) in their work to develop a methodological framework for interdisciplinary research are quick to make reference to various factors – such as the differences in epistemologies, skills, and competency of scientists, institutional contexts, and the design of collaboration structures – as success or failure factors. This, however, does not invalidate the understanding that interdisciplinary studies provide the avenue for adopting multiple lenses to investigate most phenomena. Schary and Cardinal (2015) reiterate that interdisciplinary research is a synthesis of concepts, models, and/or theoretical frameworks from two or more distinct academic disciplines. Adopting an interdisciplinary approach to research allows for the innovation and creativity deemed necessary in recent literature (Bromham, Dinnage, & Hua, 2016; Khan, Choudhury, & Uddin, 2019). In water management (sometimes classified as a boundary concept) research, we see a new crop of interdisciplinary researchers and methodologies being adopted (Levinson & Thornton, 2003; Mollinga, 2008).

I adopted an interdisciplinary approach to understand both technical and social dimensions of the climate–water–food problem. To do this, I collaborated with another PhD candidate at some points along the research process and worked with an interdisciplinary supervisory team sharing knowledge from diagnosis of the research problem, empirical studies, and scientific writing on research findings (Benton, 2013). Largely, the EVOCA project revolved around an interdisciplinary framework composed of PhD supervisory teams and PhD candidate selection for each case study.

1.5.1 Research design: qualitative case study

Qualitative studies are useful to the extent that they allow for understanding the meaning of situations and contexts and the identification of new unanticipated phenomena, processes, and – to a degree – explanations for causality whilst engaging with a small number of people (Lambert & Lambert, 2012; Maxwell, 2008). Investigating the 'why' and 'what' of water management in food systems invites the use of qualitative research designs such as a case study in interdisciplinary research, to understand processes and meaning rather than measuring in terms of quantity or frequency (Dewulf, Francois, Pahl-Wostl, & Taillieu, 2007; Thomas, 2011). A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context using multiple sources of evidence (Yin, 2003). Two common case study approaches are found in qualitative research: a social constructivist approach informed by the works of Stake (2008) and Merriam (2009); and a post-positivist viewpoint seen in the works of Eisenhardt (1989), Flyvberg (2011), and Yin (2003). As a study design, a case study is defined by an interest in individual cases rather than in the inquiry methods used (Hyett, Kenny, & Dickson-Swift, 2014).

This dissertation leans towards a social constructivist approach, with inductive interpretation of data, as described by Walsham (1995) in his study on the use of computer-based information systems. Walsham, with reference to what Giddens (1984) described as a 'double hermeneutic', indicates that researchers could influence those being researched when in-depth case studies are carried out over a long period of time. However, the process also builds trust and enables frankness in responses from those engaged in the field. We see the emergence of qualitative approaches in investigating technology adoption and use in agriculture systems in the works of Mackrell et al. (2009) and Doss (2001). Using a qualitative case study design, I studied the context over a long period of observations in the field. Spending time with farmers directly in the district over three different cropping seasons increased community acceptance and the willingness of stakeholders to engage, as I became not just an observer but also a participant in the system. The approach afforded me the opportunity to establish deeper meaning through observations and continuous daily interaction with farmers, water managers, and community leaders. Ultimately, the point of co-producing a design and content concept for a second generation climate information system emerged from a cumulative joint process of diagnostics of context through the lens not just of the researcher, but also of those been researched.

1.5.2 Data collection and analysis

In this dissertation, I use mixed methods to gather relevant data from within both rainfed and irrigated rice farming systems. Case study research designs allow for flexibility in methods dependent on research questions to be addressed at each point. The use of mixed methods permits the information from one method to throw light on the interpretation of findings from other methods (Dattilio, Edwards, & Fishman, 2010). I employed qualitative data collection methods including focus group discussions (FGDs), interviews, and observations to address RQs 1, 2, and 3.

To address RQ 1, I used interviewed guides in engaging farmers and stakeholders involved in agriculture information provision to answer design questions as part of an ex-ante assessment. I also organized FGDs with farmers in selected communities within the district for insight into technology use and an overview of social constructions. To answer RQ 2, I engaged rice farmers in communities first via direct interviews using interview guides to establish how governance arrangements inform decision-making in adapting to change, be it social or bio-physical, and I also organized FGD sessions for in-depth deliberations to support findings from individual interviews. I also observed farmers' practices within communities. For RQ 3, farmers and information service providers were also engaged exploratorily through FGDs and direct interviews. However, I additionally adopted a quasi-experimental approach (scenario workshops) to answer RQ 3 by simultaneously varying information parameters relevant for farmers in a climate information system in the spirit of testing a model of a functional system. The data in Chapters 2 to 5 were analysed by content (Hsieh & Shannon, 2005; Krippendorff, 2018) and theme (Nowell et al., 2017). The specific application of these methodologies in data collection and analysis can be found within the chapters. This is summarised in Table 1.1.

Table 1.1: Research methodology and tools

1.5.3 Case study characteristics

Research question	Chapter	Sub-questions (SQ)	Data collection	Data analysis
1	2	SQ1: Scoping SQ2: Information system design SQ3: Design elements	-Literature review -Interviews -Focus group discussions	-Document analysis -Thematic analysis -Content analysis
2	3	SQ1: Decision-making SQ2: Governance arrangement SQ3: Adaptive decision-making	-Interviews -Focus group discussions - Observations	
	4	SQ1: Evidence of logics SQ2: Uncertainties and decision-making SQ3: Impact on information needs	-Interviews -Focus group discussions	
3	5	SQ1: Information systems and information gathering SQ2: Systems and actionable knowledge creation SQ3: Actionability of knowledge	-Interviews -Focus group discussions - Observations	
	6	SQ1: Forecast information source preference SQ2: Forecast information and probabilities SQ3: Impact on information needs	-Scenario workshop	

Kumbungu District in Northern Ghana, with Kumbungu as its capital, was carved out of the Tolon-Kumbungu District in 2012 with Legislative Instrument (L.I) 2062. The district shares a boundary with Tamale Metropolis to the South, West Mamprusi and West Gonja to the North, Savelugu/Nanton municipality to the East, and Tolon district to the West, respectively. Figure 1.3 shows the district in a regional context. The district lies between latitudes $9^{0}15$` and $10^{0}02$` North and longitudes $0^{0}53$`and $1^{0}25$` West. The vegetative cover is Guinea savannah interspersed with short drought-resistant trees and grassland (Asare-Bediako, Showemimo, Buah, & Ushawu, 2007). As at 2010, the population and housing census report indicates that the district had a population of 56,166, with an even composition of both males and females in percentage terms.

The district is drained by the White Volta and other water bodies including the Bontansi river. Rains in the district begin in May and end in the latter part of October, with July to September as peak periods. Average annual rainfall within the district is 1000mm. The temperature is warm, especially between February and April. Soils are of sandy loam with a few alluvial deposits in the district’s lowlands. Soil erosion and the perennial bush burning of vegetation leaves soils exposed to high temperatures, destroying soil fauna. The district is agrarian, with most inhabitants engaged in crop production and animal rearing. Major crops cultivated include rice, yams, maize, beans, groundnuts, tomatoes, peppers, and green leafy vegetables. A few residents are also involved in fishing on the White Volta (Alhassan et al., 2013).

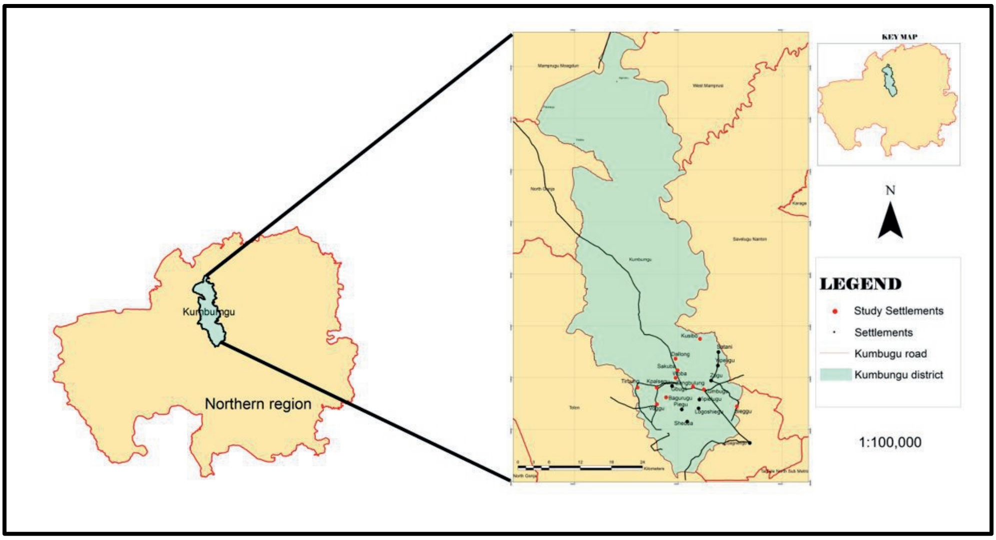


Figure 1.3: Map showing Kumbungu district in a regional context

The district is home to one of the major irrigation schemes in the Northern Region. The Bontanga Irrigation Scheme was set up between 1978 and 1983 (Zakaria et al., 2013). The scheme's water source is the Bontanga River, a tributary of the White Volta. The scheme has a potential cover area of 800 hectares, with 450 hectares of irrigable land covered as at 2014. Of the total land area, 240 hectares are used for lowland rice cultivation and 210 hectares for upland vegetable production (Braimah, King, & Sulemana, 2014; Kuwornu & Owusu, 2012).

The dissertation focuses on Kumbungu District and specifically on communities in the vicinity of the Bontanga Irrigation Scheme – as it offers the opportunity to investigate water management complexities within both irrigated and rainfed farming systems. Secondly, the district offers an avenue to augment research on technology adoption by diverse farmers in Northern Ghana (Azumah, Donkoh, & Awuni, 2018; Nchanji, Müller, Günther, Schritt, & Lueb, 2018; Obeng, Gumah, & Mintah, 2019).

1.6 Structure of the thesis

This dissertation is comprised of seven chapters including this introductory chapter. Chapter 2 sets the tone for the exploratory study towards designing a second generation climate information system by providing in-depth findings on design compositions of existing information systems in the study area. The chapter also provides insight into bio-physical conditions in the study area. Chapter 3 presents in-depth findings on governance arrangements and decision-making by rice farmers both within and outside the irrigation scheme. It establishes the existence of rules, be they formal or informal, and presents an understanding of adaptive decision-making by farmers in response in dealing with water scarcity conditions. In Chapter 4, the dissertation discusses findings on how actionable knowledge is created in rice farming systems with the support of information systems and contributes to its conceptualisation. This is critical in addressing research gaps on what is of significance to farmers in the bid to apply new knowledge in decision-making. In Chapter 5, the dissertation further conceptualises adaptive decision-making, providing an insight into how uncertainties and different decision logics come into play in adaptive decision-making. Chapter 6 presents a shift from exploratory studies in earlier chapters to an experimental insight into what information should be considered in a functional second generation climate information system. Finally, Chapter 7 summarises the discussions, providing the interconnection between findings and research questions. It also suggests further areas of research relevant for understanding how information could be made more relevant in farming systems through technology. A summary is shown in Figure 1.4.

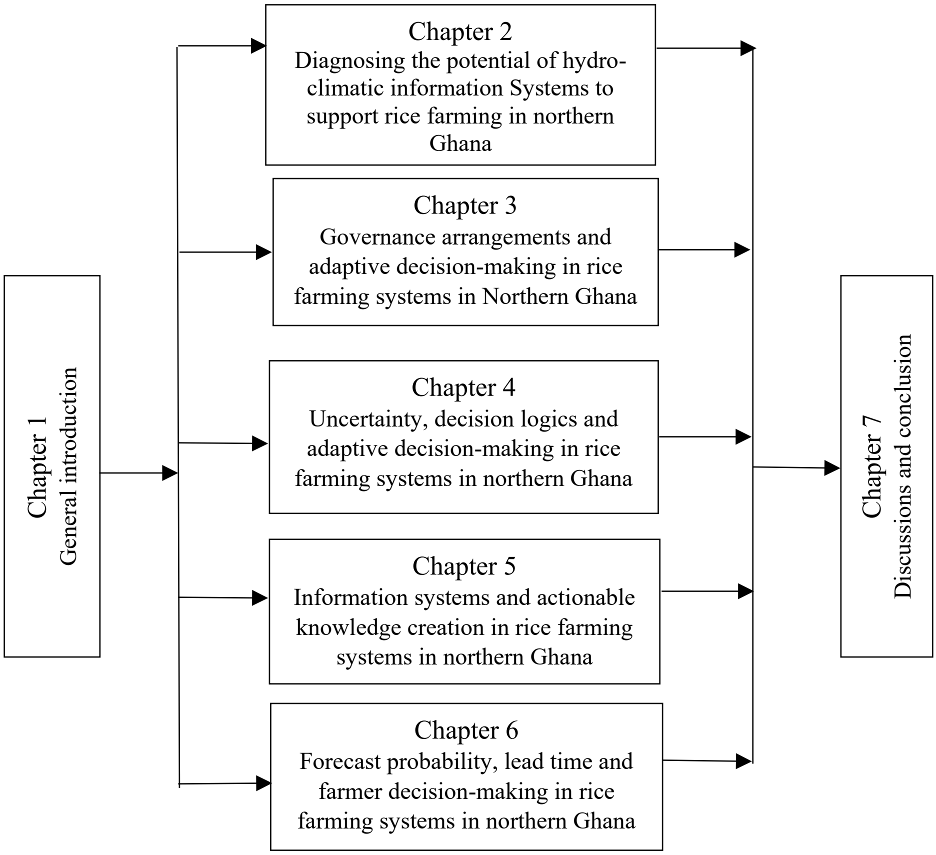
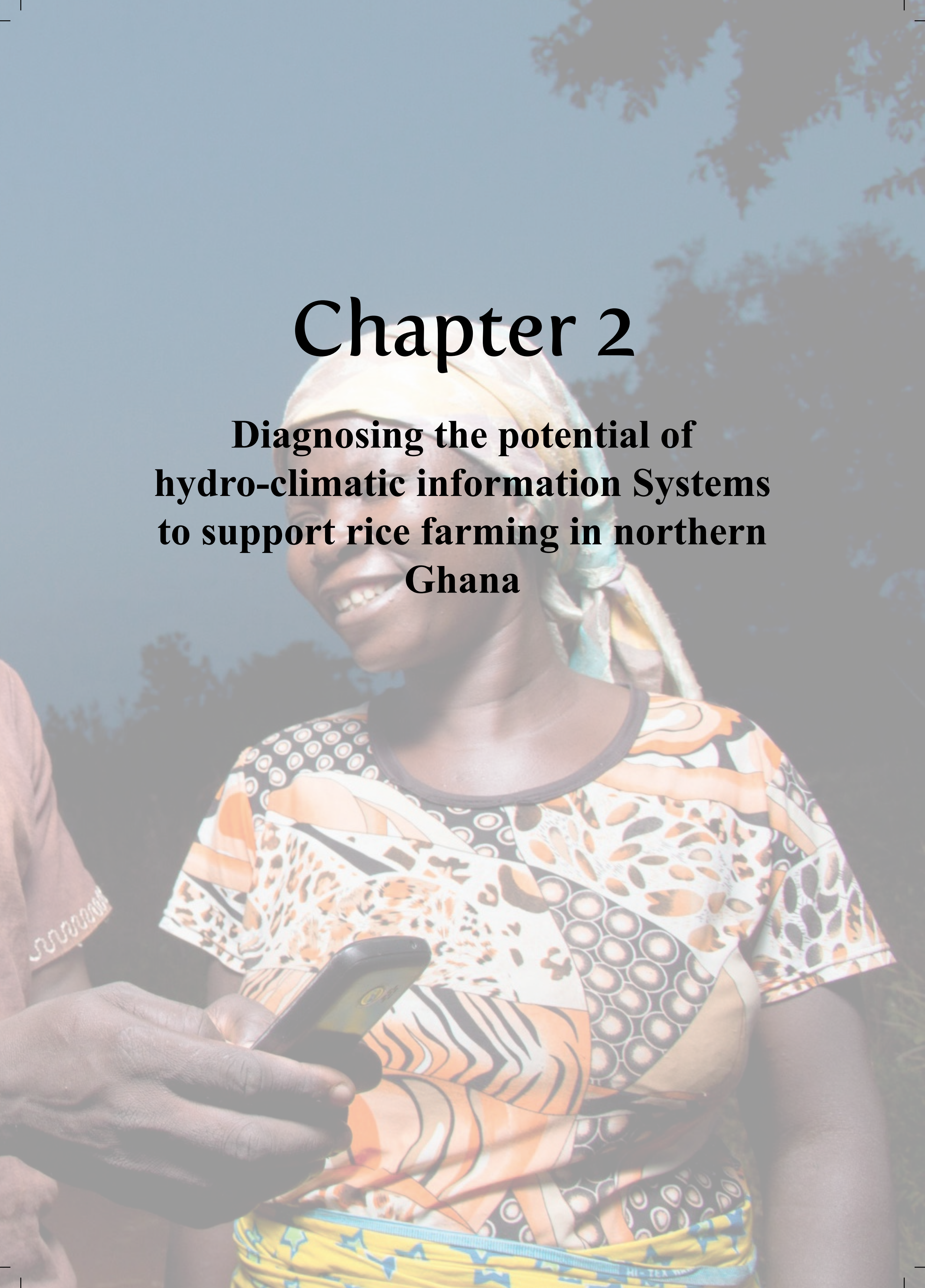


Figure 1.4: Structure of the thesis

Chapter 2

Diagnosing the potential of hydro-climatic information Systems to support rice farming in northern Ghana



Chapter 2

Abstract

Hydro-climatic information has a potential to improve agricultural productivity under climate variability. Recent developments in information sharing platforms (Environmental Virtual Observatories, EVOs) could make information provisioning more actionable. Here we present the results of a diagnostic study for the development of a hydro-climatic EVO that enables rice farmers in Northern Ghana to deal with climate variability and water shortage. The hydro-climatic EVO aims to combine data from scientific and indigenous forecast systems, facilitating information exchange using two-way interaction with stakeholders to co-produce knowledge. Data was collected through informal interviews with field practitioners, through focus group discussions with farmers and content analysis of documents. Results show that both the biophysical and socio-institutional circumstances need be taken into account for the development of the EVO. Existing governance and information exchange arrangements and lack of collaboration between actors were found to limit current hydro-climatic information flow, interpretation, and use. Our study reveals existing models of information exchange and their limitations in the study area. We discuss the proposed design of a hydro-climatic EVO from a responsible innovation perspective, considering possible future eventualities in a process that aims to be anticipatory, inclusive, reflexive and responsive. We conclude that such a hydro-climatic EVO has a potential to contribute to rice farmers' adaptive decision-making in Northern Ghana, but there are challenges that need to be considered. The diagnostic study has helped to refine these challenges and offers concrete suggestions to improve both the design and implementation of the proposed platform in a responsible way.

Published as: Nyadzi, E., Nyamekye, A. B., Werners, S. E., Biesbroek, R. G., Dewulf, A., Van Slobbe, E., ... & Ludwig, F. (2018). Diagnosing the potential of hydro-climatic information services to support rice farming in northern Ghana. *NJAS-Wageningen Journal of Life Sciences*, *86*, 51-63

2.1 Introduction

Due to increased anthropogenic greenhouse gas emissions the global temperatures are rising with a change in global water cycle resulting in more erratic precipitation patterns. Consequently, both soil and surface water availability is becoming less reliable. This increased climate variability is affecting smallholder farmers in sub-Saharan Africa. Currently more than 600 million people in rural communities in sub-Saharan Africa depend on agriculture for their livelihoods (Rockström & Falkenmark, 2015). Many farmers are struggling to cope with challenging conditions, which result in low yields and food insecurity (Di Falco, Veronesi, & Yesuf, 2011). One of the main problems for food production in Africa is large-scale climate variability. Both inter-annual and seasonal rainfall variability are a challenge for farming decision-making in Sub- Saharan Africa. Future climate change caused by increased greenhouse gas emissions are likely to result in changing rainfall patterns.

Similar to other countries within Guinea and Sudan Savanna agroecological zones, Ghana is vulnerable to climate variability and change (Africa Partnership Forum, 2007). The agricultural sector depends heavily on rainfall that varies annually and seasonally. This significantly affects soil water availability for crops and increases the risks for low crop production and failure (Kunstmann & Jung, 2005; Asante & Amuakwa-Mensah, 2015). Meanwhile the agriculture sector is very important for the economy of Ghana, employing 44% of the work-force and accounts for nearly one-quarter of GDP. The degree of community vulnerability and crop failure is greatest in its three northern regions, namely Upper East, Upper West, and the Northern region. Farmers in these regions are faced with many uncertainties prior to every growing season, most of which are attributed to water and climate variability (Gbetibouo, 2009).

Due to increasing climate variability farmers struggle about decisions such as seed variety to plant, when to plant, when to fertilize, when to do supplementary irrigation and sometimes when to harvest. According to Ndamani and Watanabe (2014), a farmer usually starts to make preparations for planting crops with the onset of the rainy season. After months of drought, the soil is dry and hard. In the month of May, the farmer starts to look into the sky every day expecting the first rain clouds to appear, which would indicate the beginning of the major production season. When the rain finally comes, the farmer starts to plough his land and plants his crops. But his mind is filled with worry. How much rain will there be this year? Will there be another dry spell shortly after the first rain, which could destroy the seedlings? Would it be better to wait and start seeding later? He recalls, however, that two years ago, there was no dry period in May and a heavy rain washed away the seeds that he had planted too late.

Finding solution to these dilemmas of a typical farmer is vital and urgent. Several studies have predicted the future climate of Ghana to be more variable and uncertain, making the agriculture sector more vulnerable (Kankam-Yeboah, Obuobie, Amisigo, & Opoku-Ankomah, 2013; Obuobie, Kankam-Yeboah, Amisigo, Opoku-Ankomah, & Ofori, 2012). Recent progress in climate modelling has increased the ability to predict rainfall from a few days to seasonal forecasts (Njau, 2010). Being able to predict the weather and climate especially rainfall is indispensable for guiding water users, especially farmers in their planning and decision making (Logah, Obuobie, Ofori, & Kankam-Yeboah, 2013). Empirical studies have shown that climate forecasts can help farmers reduce their vulnerability to drought and climate extremes, while also allowing them to maximize opportunities when favourable conditions are predicted (Patt, Suarez, & Gwata, 2005; Phillips, Makaudze, & Unganai, 2001; Roncoli et al., 2009).

The underlying assumption in the current practices of hydro-climatic information services is that if we provide the farmer with more and better information, they would be able to improve their farming practices (Etwire et al., 2017; Anoop, Ajjan, & Ashok, 2015; Okello, Kirui, Njiraini, & Gitonga, 2012). This one-directional model of providing climate services has shown to be flawed, as farmers tend not to trust scientific information and experience difficulties in interpreting and using it. They are therefore confident that their indigenous systems work better (Hartmann, Bales, & Sorooshian, 1999; Letson et al., 2001; McNew, Mapp, Duchon, & Merritt, 1991). Efforts to train farmers to adopt this model of providing climate services generally fail to improve the uptake of climate information (Manyanhaire, 2015; Patt & Gwata, 2002), because providers also have little understanding of users, and what drives the influence of indigenous forecasts (Artikov et al., 2006).

We however argue that science should not be a one directional effort, where science produces new knowledge and information and makes it accessible for end-users. Instead, the process should be interactive, where science and practice co-design, co-create and co-produce knowledge by bringing in different forms of expertise. The latter would result in better appreciation of the scientific expertise as well as indigenous knowledge necessary to improve societal resilience to climate change (Hiwasaki, Luna, Syamsidik, & Shaw, 2014; Hiwasaki, Luna, Syamsidik, & Marcal, 2015; Mazzocchi, 2006). Increasingly there are calls for involving farmers not only as end-user, but as an active participant who is not only involved in use of the information, but also in the creation of it.

Environmental Virtual Observatories (EVOs) aim to enable cross-fertilization of different sources of environmental knowledge on web based virtual platforms, incorporating information gathering, processing and dissemination technologies (Karpouzoglou et al., 2016a). The first generations of these systems aimed to support the scientific process of knowledge creation and mainly targeted scientific audiences. They failed to deliver a strong knowledge creation component especially in information generation and dissemination projects that seek to empower local communities to manage their environmental change using actionable knowledge (Dewulf et al., 2005). Hence, several authors have proposed second generation EVOs that emphasize knowledge cocreation between scientists and societal actors, and bidirectional information flows, so as to create actionable knowledge that can support decision-making (Karpouzoglou et al., 2016a). However, these systems are place based and context sensitive, requiring a thorough understanding of the potential to uptake co-develop, co-produce and co-implement such hydro-climatic information systems.

As part of a larger endeavour, we aim to design a “second generation” information system in the form of a hydro-climatic information system called a hydro-climatic Environmental Virtual Observatory. This system will use data from the scientific seasonal climate forecast ECMWF-4 (European Centre for Medium-Range Weather Forecasts-system 4) model, complemented with farmers indigenous forecast collected through citizen science (Pettibone et al., 2016) to generate actionable knowledge for adaptive decision making in rice farming systems. Karpouzoglou et al. (2016) indicate that in the context of emerging open-technologies for information exchange, added value can be achieved by removing institutional and geographical barriers associated with information flow.

In this paper we aim to diagnose the socio-ecological settings of rice farming systems in northern Ghana in the context of climate variability and change to ensure effective design and operationalisation of hydroclimatic EVO. We first conduct a diagnosis of the socio-ecological settings of rice production system in Northern Ghana in the context of climate variability and change. In the next step, we elaborate the diagnostics by focused on hydro-climatic information needs and use in rice based farming systems. Based on these diagnostic steps, we identify the specific challenges and opportunities identified in our case region, which could be meaningfully addressed by a potential EVO. We used the four dimensions of Responsible Innovation to reflect on the robustness of the design and processes of hydro-climatic EVO to deal with the challenges and opportunities faced in a responsible way. The outcome of our study is a framework for the hydro-climatic EVO outlining its properties and processes.

2.2 Conceptual framework

Studies show that crop management strategies of farmers (e.g. timing of planting, weeding, fertilizing, application of pesticides) are shaped by predictive weather/climate information. Traditionally farmers make use of indigenous knowledge to produce seasonal and weather forecast (Svotwa, Manyanhaire, & Makanyire, 2007). Traditional Ecological Knowledge (TEK) is known by a wide variety of terms, including indigenous knowledge (IK), local knowledge (LK) and traditional knowledge (TK). It has many definitions and there is no consensus on an operational definition applicable across disciplines. Huntington et al. (2004, p. 1270) for example, understand TEK as '…the knowledge and insights acquired through extensive observations of an area or species'. In contrast, Berkes et al. (1994) in an attempt to more fully incorporate indigenous world views, broadens the scope of TEK and define it as '…a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment (Berkes et al., 1994, p.7). In the context of this study, emphasis is placed on "indigenous", which is defined as native or local knowledge that is passed on from generation to generation. Indigenous forecasts are based on farmers' experience of changes in certain biophysical indicators (Orlove, Roncoli, Kabugo, & Majugu, 2010; Roncoli, Ingram, & Kirshen, 2002). Literature shows that African farmers are using various local weather indicators such as plants, animals, insects, the solar system and wind in predicting the weather and climate (Speranza, Kiteme, Ambenje, Wiesmann, & Makali, 2010; Ziervogel & Opere, 2010; Tarhule & Lamb, 2003; Roncoli et al., 2002). Studies have therefore suggested that particularly in Africa indigenous knowledge has the potential to enhance farmers' adaptation to climate variability and change (Naess, 2013; Derbile, Jarawura, & Dombo, 2016; Mikkelsen & Langohr, 2004). However, it is plausible that indigenous knowledge is not sufficient anymore because of projected climate change.

Increasingly, scientific projections are developed to further inform farmers about short, medium and long-term climate variability and change, particularly for rainfall. It is important, however, to acknowledge that weather and climate forecast systems have limited value unless they can directly influence decisions and have an impact on the systems under consideration (Hammer, 2000). Manyanhaire (2015) argue for the integration of indigenous knowledge systems with climate change science as a basis for comprehensive community based response to the impacts of climate change. It is argued that farmers are more likely to adopt new ideas when these can be seen in the context of their existing practices. Patt and Gwata (2002) for example observed that farmers' willingness to use seasonal climate forecasts increased when the forecasts presented are combined and compared with local indigenous forecasts.

As indicated in the introduction, creating conditions that allow for knowledge exchange between scientists, decision-makers and citizens is becoming increasingly necessary for building resilience and responding to environmental change (Mol, 2006; Buytaert et al., 2014; Folke et al., 2010). The concept of Environmental Virtual Observatories (EVOs) offers the opportunity to bring together scientific and indigenous knowledge (Karpouzoglou et al., 2016a). Examples of first generation of these EVOs are for communicating flood risk to catchment stakeholders and a cloud technology for connecting and integrating fragmented data, models, and tools to deliver new holistic approaches to environmental challenges (Emmett et al., 2014). They have paid less emphasis on how enhanced participation of a variety of users can be achieved via a virtual platform. In many cases, projects that seek to generate and disseminate information that provides actionable knowledge for empowering local communities and enhancing environmental management for example have achieved limited success (Dewulf et al., 2005).

Despite considerable progress in recent years, many cases exist where knowledge and perspectives of certain groups of people are either not included or under represented (Karpouzoglou et al., 2016). This is particularly challenging for EVOs that exist on the interface between scientists and non-expert users. Similarly, most of the first generation EVO's are developed and communicated, using mostly top-down approaches. For example, local farmers are considered as end-users of forecast products developed by scientist from universities and/ or research institutions. In most cases, farmers do not contribute to the process of developing the weather climate forecast products (Ouédraogo, Zougmoré, Barry, Somé, & Grégoire, 2015). As a result, the communicated forecasts are often not locally specific or applicable and therefore contribute to limited action. Second generation EVOs seek to resolve this problem by enhancing participation of all relevant stakeholders.

While first generation EVOs are primed for scientists, second generation EVOs have a benefit to include knowledge co-creation and resilience through their participatory design. Second generation EVOs such as those proposed by Karpouzoglou et al. (2016a) have a greater focus on the processes of knowledge co-creation and interaction between stakeholders. An important aspect of this knowledge co-creation EVO is its potential to achieve greater relevance by engaging with stakeholders. In some cases, citizen become active contributors to science (Buytaert et al., 2014) and EVO's offer the possibility to connect scientist and local farmers via a virtual platform where information is exchanged and knowledge created to support farm decision-making. Active engagement of farmers can range from short-term collection of data to intensive engagement in creating new knowledge with scientists and/or other volunteers (Pettibone et al., 2016).

Introducing new innovations such as EVO's should be undertaken responsibly, especially when directed at socially desirable and socially acceptable ends (Owen, Bessant, & Heintz, 2013). Designing these EVOs responsibly means acknowledging that such frameworks are not only technical but are also socially and politically constituted (Winner, 1978). Innovative technologies that underlie EVO's might have great benefits for society, but unforeseen impacts are not just possible but probable. To guide the design and evaluation of our EVO, we build onto the responsible innovation concept. We make use of the responsible innovation (RI) framework of Stilgoe et al. (2013) which provides a set of basic principles that seek to maintain novelty and at the same time make it responsible: anticipation, reflexivity, inclusion, and responsiveness. Anticipation requires that researchers and organizations continuously ask 'what if?' questions, which include but not limited to what are the likely consequences? What are possible unintended effects? It requires projection and futuristic thinking in a systematic way and consideration of how the EVO is predictable and resilient to change.

For example, it provides early warnings of future unfavourable consequences and estimate risk-based harm of innovations (Hoffmann-Riem & Wynne, 2002). The second dimension, reflexivity, refers to the principle that institutions and organizations must reflect on their activities and assumptions and acknowledge that the knowledge they produce and use has limitations. How they frame issues may not be universally applicable and without reflexivity may lead to frame conflicts or unresponsiveness of stakeholders (Stilgoe, Owen, & Macnaghten, 2013; Wynne, 1993). The third dimension, inclusion, refers to the need to involve minorities and groups without a voice in the innovation process (Hajer, 2009; Felt, 2009; Stilgoe et al., 2013). Whereas the first generation of EVO's placed limited emphasis on stakeholder involvement, responsible innovation requires active involvement of different groups through dialogue and representation throughout the innovation process. The dimension of responsiveness as proposed by Stilgoe et al. (2013) requires that systems of innovation have the capacity to change or shape direction in response to stakeholder and public values and changing circumstances. Also in this article, we use the framework to evaluate the proposed hydro-climatic EVO.

2.3 Methodology

In this paper, we address the following research question: How will the existing socio-ecological setting in rice production systems in Northern Ghana promote or hinder a possible hydroclimatic EVO design and operationalisation? To diagnose our case region and analyse the potential for designing a new EVO, the study adopts a systematic approach involving five sequential steps (see Fig. 2.1). We gathered data from both primary and secondary sources using qualitative methods of data collection and analysis.

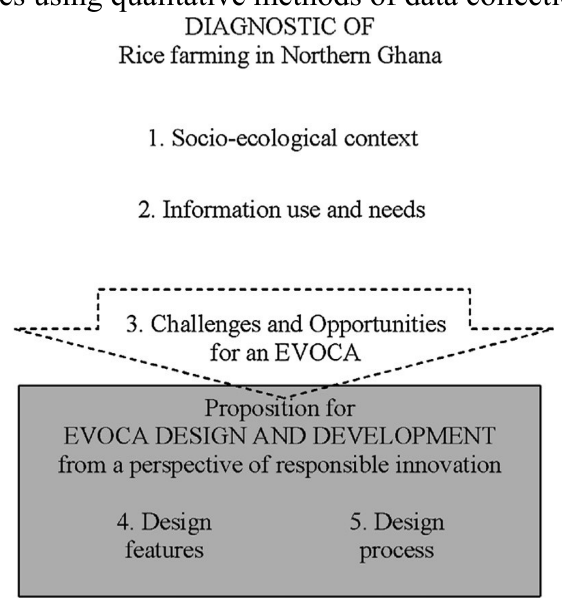


Figure 2.1: Workflow of the study.

2.3.1 Data collection

To collect data, we made use of three qualitative methods: content analysis of existing documents, interviews, and focus group discussions. The selection of methods provided us insight into the socio-ecological context of the case study, information needs and use as well as the challenges of existing systems and opportunities for the development of a hydro-climatic EVO.

a) Research literature and documents analysis:

We collected policy documents, donor agency reports, scientific research articles and research reports from related projects and programs by going through government and non-governmental organizations' websites and online repositories. We specifically focused on analysing local governance and institutional documents containing rules, structures and arrangements about farming, irrigation and water use in Northern Ghana to gain a thorough understanding of the decision-making context and practices. The data collected helped us also to guide the interviews.

b) Interviews

We informally engaged in an open conversation with fifteen (15) practitioners from nine different organizations (Table 1). To allow the discussion to move in the direction preferred by the practitioners, we opted not to use a structured interview guide, but rather semi-structured the conversations along topics emerging from the document analysis. The informal setting allowed respondents to speak more freely and openly about their experiences and helped in building relationships for future collaborations. The practitioners were purposefully selected based on their principal role (civil society representatives, policy and decision makers, researchers and farmer representatives) and expertise in climate, water management and farming. The conversation centered on five thematic areas: (i) perception of the climate-water-food production problem in northern Ghana; (ii) current actions taking by farmers and organizations to manage these problems; (iii) farmers' hydro-climatic informational needs and use; (iv) the value of seasonal climate forecast; and (v) the feasibility of hydro-climatic EVO to ameliorate the challenges. Each conversation lasted for about one hour and the information was recorded digitally and captured in a field notebook.

Table 2.1: Stakeholders engaged in informal interviews

Stakeholders	Number interviewed	Justification
1. Applied Meteorological Unit - Ghana Meteorological Agency	1	Study and provide weather, climate and meteorological advices to the general public and farmers
2. Ghana Irrigation Development Authority (GIDA)-	1	Responsible for Irrigation and water management of all irrigation projects and their development
3. Ministry Of Food & Agriculture (MoFA)- Crop Division(RSSP AND GCAP)	3	In charge of the sustainability of food and agriculture. RSSP and GCAP raise awareness and support farmers with inputs and climate related advice that boost domestic rice production and commercialize farming.
4. Irrigation Water Manager (IWM)	1	Manages the irrigation scheme at Bontanga.
5. Ghana Hydrological Services (GHS)	1	Studies water bodies in the region. Have access to historical data of river flow and other hydrological information.
6. Faculty of Agriculture and Agricultural Engineering- University For Development Studies (UDS)	2	Teach students who major in general agriculture, agriculture engineering, soil and water conservation, and irrigation science. Train farmers and Conduct research into climate, water and agriculture related issues.
7. Rice Farmers Association (APEX Farmers Group)	2	Members are mainly into rice production in Bontanga.
8. Savannah Agricultural Research Institute (SARI)	2	Train rice farmers on appropriate agronomic practices. Introduce rice varieties to farmers and conduct climate and agriculture related research.
9. Agriculture and Development Non-Governmental Organization (IFDC and JICA)	2	Train and support farmers with inputs and advices that will promote local food production including rice production
Total	15	

c) Focus Group Discussions

To collect information about the challenges farmers experienced through the existing governance arrangements, water management practices, information management and decision-making, we organized seven Focus Group Discussions (FGDs) with farmers who were engaged in irrigated and/or rainfed rice farming within the Kumbungu District. FGDs were held at the farm, community and scheme levels. Discussions at the farm level focused on the perception of farmers on problems of the climate-water-food production nexus and steps taken to manage them. In addition, discussions revolved around the hydro-climatic informational needs of farmers.

To broaden the scope, the FGDs organized at the community level included rice farmers, traditional leaders, political representatives and women. This allowed us to discuss the place of hydroclimatic information in their farming cycle, as well as the ways in which governance arrangements and decision-making processes at the community and farm level worked. At the scheme level, similar questions were asked to inquire on the activities of rice farmers within the Bontanga Irrigation Scheme about governance, water management and how that impacted decision-making. Participants were leaders of farmer associations, the manager and representatives of committees (see Table 2.2).

Table 2.2: Actor groups for focus group discussions.

Target group	Definitions	Characteristics of the FGD
Rice Farmers	Farmers who cultivate rice under rainfed or irrigated farming systems or both	-FGD with rainfed rice farmers -FGD with irrigated rice farmers
Community Leaders	Individuals with leadership authority established by written or unwritten laws within the community.	-FGD with Traditional leaders -FGD with local political leaders -FGD with leaders of independent organization within the community
Water Managers	Individuals responsible for production, process and delivery of water for use on rice farms.	-FGD with farm level actors such as water bailiffs, carnal supervisors under irrigated rice production system
Leadership of the scheme	Public servants leading operations under within the scheme as wells as committees	-FGD with scheme lead, engineer, financial manager, leaders of farmer associations and committees

2.3.2 Data analysis

Literature and available Documents were analysed in two stages; we first scanned existing literature and documents for relevant information from empirical and theoretical perspectives. Next was a synthesis of information Secondly, we thoroughly examined them by reading, extracting and synthesising key information from the selected literature and documents; background information of rice farmers as well as insight into the socio-ecological settings of rice production systems in Northern Ghana. It also provided supplementary research data on the importance of rice in the economy of Ghana, historical and current climatic variability and change in Northern Ghana as well as model projections of these changes and their undesirable impact on farmers was established. In addition, arrangement and rules governing rice farmers' activities in Northern Ghana and the management framework of the irrigation schemes including existing hydroclimatic information systems and their value to rice farming was obtained via literature and document analysis.

Using Atlas.ti (Hwang, 2008), we used open-coding methods and clustered the topics of the several themes. The analysis was aimed at first verifying our findings from the literature and document analysis to corroborate evidences and secondly to probe further on arising issues such as practical challenges of climate variability and change for farmers and the potential value of hydro-climatic information systems for farmers' adaptive decision making.

Focus Group Discussions were similarly transcribed and processed through thematic analysis. The analysis provided information on the rules of engagement and decision making among rice farmers, their knowledge of existing hydro-climatic information services, information access and utilization, challenges of institutional linkage and information exchange at farm level.

2.4 Results

2.4.1 Diagnostic analysis of the social-ecological system

To analyse the current setting, we focus on rice farmers in Northern Ghana (Fig. 2). We specifically explore the socio-ecological aspects of climate change impacts on crop productivity (i.e. yield per unit area) and not 'food production', as this is dependent on many other factors than climate change, such as quality of land, infrastructure investment, available finance, international trade policy, and food market. We analyse this case region by splitting it in two dimensions; the biophysical factors (climate and water) and socio-institutional (actors, rules, practices, decision-making) parameters framing the activities of rice farmers within the study area.

i) Biophysical context

From the literature analysis and interviews, the major The biophysical issues in the case area are mapped in Fig. 3. The main issue in the North of Ghana (~97,702 km² land area) is climate variability which significantly impacts agricultural productivity. Development of the agricultural sector in this region is affected by the climatic conditions, such as the long dry season of about six to seven months followed by five-month rainy season (April/May to September/October) usually characterized by sporadic droughts and/or floods (Amikuzino & Donkoh, 2012; Barry, Obuobie, Andreini, Andah, & Pluquet, 2005). Temperatures in the region are higher compared to those in the southern part of the country. The lowest maximum temperatures are around 26 °C mostly recorded in August and highest temperatures are between 40–42 °C recorded in March or April (Mdemu, 2008). The climate system of Northern Ghana is characterized by distinctive inter-annual and inter-decadal variability in precipitation and temperature (Nyadzi, 2016). The area is associated with an erratic unimodal rainfall of an annual sum between 400 and 1200 mm. Changes in the duration of the rainy season have shortened the length of the growing season, delaying the onset of planting season in most cases, while dry season and rainy season temperatures have increased by about 1 °C and 2 °C respectively (Acquah, 2011; Kunstmann & Jung, 2005).

The northern part of Ghana experiences the greatest rainfall variations and this is projected to increase along with increasing temperature (2.1–2.4 °C) from 2010 to 2050 (Owusu & Waylen, 2009). According to Kankam-Yeboah et al. (2011), high temperatures that were previously recorded in March (peak of the dry season) are now being recorded also in January. In addition, the onset of the rainy season has become more difficult to predict. They also indicated that in the past, the rainy season started in April and ended around late September or early October. However, in recent times, the rainy season starts in June or July with extreme heavy rainfall in September or October.

These outcomes indicate a potential increase in the intensity and frequency of extreme events, such as droughts and floods and a consequential reduction in the crop growing period with serious implications for crop yields and food security (Abdul-Rahaman & Owusu-Sekyere, 2017; Kasei, Ampadu, & Yalevu, 2014). Current occurrences and long-term climate patterns create future uncertainties with serious implications for climate prediction and agricultural productivity. As re-iterated by Antwi-Agyei et al. (2012), climate variability, manifested at different time scales and in different ways will significantly impact the agricultural sector of Northern Ghana.

In addition, large temporal and spatial rainfall variability results in high variability in river flow. As results, most rivers flow for only a few months a year with limited or no flow during the rest of the year (Amisigo & van de Giesen, 2005). The combination of climate change, intensive land use, population growth and economic development results in increased water demand and more pressure on the available water resources (Stanturf et al., 2011). To cope with climate variability hydraulic infrastructure such as small-scale reservoirs and large scale irrigation systems have been constructed mainly for agricultural purposes (Faulkner, Steenhuis, De Giesen, Andreini, & Liebe, 2008; Amisigo, McCluskey, & Swanson, 2015).

Uncertainties related to climate variability is a major challenge for both rain-fed and irrigated farmers and water managers because to productively manage their activities, critical climate sensitive decisions have to be taken months ahead of a season (Asante & Amuakwa-Mensah, 2015). Sustainability of rainfed farming systems becomes a challenge with severe impacts on crop yields (Fosu-Mensah et al., 2012; Acquah, 2011). Not only does this affect rain-fed farming, it also has a major toll on irrigation schemes. Water levels in the dry season are low making it difficult to irrigate farmlands limiting production. Farmers have reported re-sowing of seeds due to poor germination following delay in rains, which increases their cost of production. Irrigation water managers rely on river discharge to decide the frequency, quantity and method of water distribution. The uncertainty associated with predicting seasonal rains and water availability puts farmers in a dilemma when key farming decisions are to be made (Ndamani & Watanabe, 2014).

In the face of these challenges, rice is a central crop as it accounts for 15% of agricultural output and 45% of the total area used in cereal grain production in Ghana (Stanturf et al., 2011). Rice is produced under irrigation, rain-fed lowland and rain-fed upland systems. Studies on climate change project increasing temperatures and declining rainfall, resulting in reduced rice production (see Asante & Amuakwa-Mensah, 2015). In a study carried out by Knox et al. (2012) rice is projected to experience the most variations of all studied crops, since water scarcity, and over reliance on unpredictable rainfall are the major factors affecting rice production in Northern Ghana (Kranjac-Berisavljevic, Blench, & Chapman, 2003).

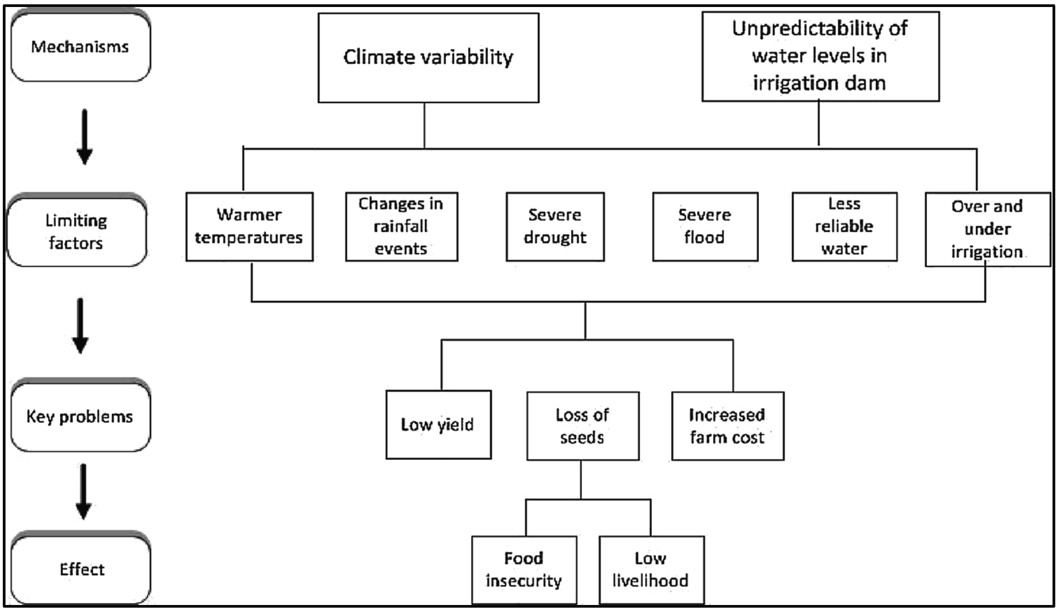


Figure 2.2: Analysis of the main biophysical issues in northern Ghana

ii) Socio-institutional context

The North of Ghana is divided into three administrative regions: Upper East, Upper West and Northern Regions (Fig. 2.3). The majority of this area is located in the Tropical Guinea Savannah zone, with small parts (extreme north of the upper east and west regions) sharing border with Burkina Faso in the Sudan Savanna. The north of Ghana is the poorest part of the country yet recent reports indicate that about 80% of the economically active population in this part of Ghana engages in agriculture, producing millet, guinea-corn, rice, maize, groundnut, beans, and sorghum with some few others producing dry season tomatoes and onions. Livestock and poultry production are also common in the region. The north of Ghana is generally endowed with about 20 small and large irrigation schemes. Rice farming periods and practices are similar across the three regions, even though there are individual preferences for different varieties depending on farmer's own aim of farming (Braimah et al., 2014).

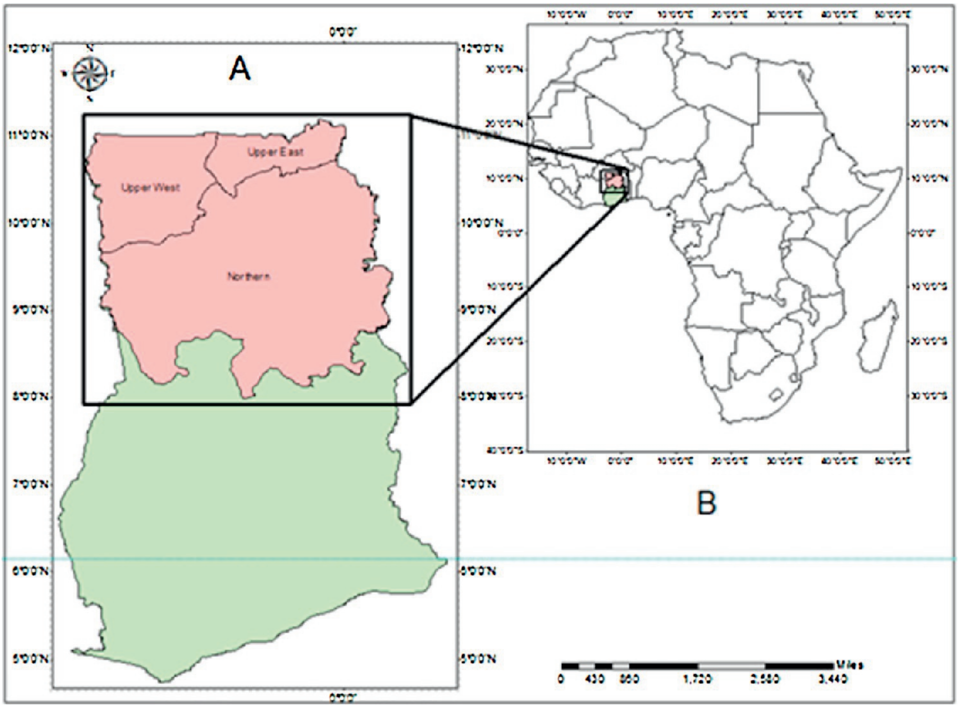


Figure 2.3: Northern sector of Ghana in a black rectangle (A) relative to Africa showing Ghana (B)

Governance in Ghana is characterized by two main governance arrangements. These are traditional and formal arrangements. Formal governance arrangements have been established by legal and structural definitions captured in the constitution and other working documents dependent on the context. Traditional governance arrangements, although ‘loosely’ framed are embedded in local and community culture expressed in the form of rules, norms and beliefs (Myers & Fridy, 2017). In Northern Ghana, the activities of rice farmers are informed by both governance arrangements (Nanedo, Prior, de Bruyn, & Marshall, 2014).

Our engagements revealed that the Ghana Irrigation Development Authority, has the mandate of developing and managing irrigation infrastructure (see Namara, Horowitz, Nyamadi, & Barry, 2011). The Ghana Meteorological Agency, Water Resource Commission and the Center for Scientific and Industrial Research are also collaborative institutions in meeting information, water security and advice on crop productivity respectively (see also Braimah et al., 2014; Nanedo et al., 2014). The Participatory Irrigation Management Strategy adopted in the 1990s has served as the framework for a more decentralized management of Irrigation Schemes. At the scheme level, the manager is responsible for the daily operations of the scheme and thus engages farmers and leadership of farmer associations in the drafting of schedules and assigning of roles for effective water management for irrigation purposes. Water is thus discharged through canals onto farmlands within different laterals guided by agreed schedules. The manager also coordinates decisions and information exchange amongst all actors as part of steps to adapt to changing conditions experienced (Namara et al., 2011).

Rainfed rice farmers operating within communities are also guided by traditional governance arrangements aimed at ensuring effective engagement and resource use. These are in the form of rules and procedures which community members are expected to adhere to or live by. For example, Chiefs are custodians of lands and thus farmers who do not have family lands would have to consult the leadership for land for farming activities. Water is also perceived as a communal resource and hence farmers are expected to consider the interest of other users in the quest to meet their water needs. Chiefs who are thus seen to have the highest authority within the community legally enforce communal decisions. Farmers must thus adhere to agreed rules even if it does not satisfy their needs.

In both systems, we found the existing governance arrangements to be arrangements to be faced with multiple challenges limiting stakeholder interaction and information exchange. For instance, information provision through Chief are usually aimed at general community concerns and activities rather than agriculture information required for farm decision-making. Most farmers thus took the initiative of obtaining information from other farmers or platforms such as radio and mobile telecommunication service operators involved in related information provision (see also Alhassan et al., 2013). Community representatives such as Assemblymen are not instrumental in providing relevant farm related information. Within the irrigation scheme, power play and gender imbalance results in bias in engagement. Results of the focus group discussions show that access to water was mostly characterized by power play especially during the dry season as only a few laterals upland could access water for irrigation from the dam. Thus, lands in the upland are allocated to cronies of the irrigation manager, chiefs and heads of committees. Women are also less represented and hence limited in accessing land and obtaining relevant information related to farm activities. Governance arrangements within the scheme also put the Scheme manager in charge of information directly relevant for scheme operations. In some contexts, farmers receive delayed information relevant for decision-making due to inactivity on the side of leadership. Interviews and FGDs pointed to weak institutional collaborations especially on information provision and use (see also Nugent, 2000). A situation largely attributable to negligence, poor leadership, weak communication links, inadequate resources and logistical challenges. For example, the Ghana Meteorological Agency provides seasonal climate information only at the start of the season and mostly to radio stations and irrigation scheme managers with little contact with farmers themselves. However, wherever these contacts exist they are inconsistent and generally decrease over the season. Private operators providing hydro-climatic information have limited collaboration with the public sector. Thus, ESOKO, MTN and Vodafone only interact with farmers without consideration of existing programmes and how their interventions could be embedded in them. Braimah et al. (2014) allude to complex local socio-political issues that affect relationships within irrigation schemes. These range from power play to gender inequalities affecting knowledge exchange and resource management.

Interviews also revealed that farmers take a number of key decisions in managing changes in climatic conditions and how they affect water availability and food production. These include when and how to prepare farmlands, when, what and how to plant, perform weed control, apply fertilizer and harvest. Farmers adapt their decisions considering outcomes and what is deemed appropriate in a given context (see also Ndamani & Watanabe, 2014). Under irrigated rice farming, water managers lead the decision process with the design of an irrigation schedule. Farmers however are responsible for specific decisions on their farms. Under rain-fed systems, the farmer leads the risk management process by exploring how experience from the previous season and new knowledge or information on weather inter alia, water availability in their decision-making (see also Abdul-Razak & Kruse, 2017). The survey revealed that adaptive farm decisions of farmers are generally based on information generated from indigenous and scientific forecasts. While farmers were quick to acknowledge the limitations in their personal forecast they however considered it better for decision making than the scientific forecast provided by Ghana Meteorological Agency as this was perceived to be generic and not locally specific to their community and needs (see also Gwenzi, Mashonjowa, Mafongoya, Rwasoka, & Stigter, 2016; Zuma-Netshiukhwi, Stigter, & Walker, 2013). Information systems within the study area were identified to provide scientific forecast information whereas indigenous forecasts were tied to farmers observation matched with experience. For example, farmers are able predict the beginning of the wet season and when to prepare their fields for planting (Ofori-Sarpong, 2001). They base their predictions on a set of indicators, each of which has different levels of reliability. The flowering of the shea nut tree, migratory patterns of birds and position of the constellation Pleiades all help farmers determine when the rainy season is due (Benneh, 1970). They are able to predict date of seasonal rainfall onset and cessation, and whether the season will receive above, below and normal rainfall. Also, they are able to make daily weather predictions of low, medium and high rainfall (Nyantakyi-Frimpong, 2013). In the next section, the paper presents findings on information systems and how they enable hydroclimatic information access and use.

2.4.2 Hydro-climatic information access and use in rice farming systems in northern Ghana

The role of hydro-climatic information in knowledge creation, improved adaptation and improved agricultural production has been highlighted in different studies and initiatives (Sam, Osei, Dzandu, & Atengble, 2017; Owolade & Kayode, 2012). For example, in 2014 and 2015, the Ghana Meteorological Agency (GMet, 2016) in collaboration with the CGIAR and ESOKO provided weather and seasonal climate information via conventional SMS to farmers in two piloted communities. Other media such as radio and television programs are also used to provide relevant information in English and local languages (i.e. Dagbanli, Frafra, Gonja, Kasem, etc.).

In spite of these interventions, there are still challenges in information access and interpretation by farmers who are illiterates and can't read text and even literate farmers lack the necessary skills to understand technical information because of the format in which they are presented. Also, the extent to which those who could read adopt the information and new knowledge received is considerably questionable (see also Sam et al., 2017). Our inventory of existing ICT and media platforms in Ghana as shown in Table 1 reveals some potential information transfer models, namely radio, mobile apps, websites and conventional phone-based services (e.g. recorded voice messages and SMS texts for more literate farmers). Other non-ICT means of information transfer include moving vans, extension officers, water managers and head of farmer organizations who disseminate pertinent information to farmers. Table 2.3 provides an assessment of strengths and limitations of the main communication tools regarding their utilization in hydro-climatic information services delivery in northern Ghana.

Table 2.3: Overview of key strengths and limitations of main media platforms in hydro-climatic information services in Ghana

Communication tool	Strengths	Limitations
Radio services	-Multiple Agro-focused radio stations exists in Northern Ghana (e.g. Radio Tongu, Simli Radio etc.)[a] -Operate at the suitable spatial level/coverage and are powerful communication tools with the potential to benefit agricultural extension (Chapman, Blench, Kranjac-Berisavljevic, & Zakariah, 2003) -Most radio operators offer services in multiple local languages such as Dagbani, Mampelle, Frafra, Waali and	-Radio services offer few mechanisms for meaningful interactions with farmers. -Information reaching farmers through radio could be adulterated, as there might be difficulties in the translation of some terms into local dialects. -This will hinder information exchange between data users (farmers) and researchers of the hydro-climatic-EVO.

	Dagaare which are important for the Northern Ghana context -Farmers generally listen to local radio on frequent basis and this makes it easier to reach targeted farmers with hydro-climatic information.	
Mobile apps	- Powerful visualization capabilities in mobile apps help to overcome the challenge of limited literacy rate in rural communities (Vitos, Lewis, Stevens, & Haklay, 2013). - Our experience with developing a prototype offline mobile-app to collect farmers' short-term weather predictions in northern(on-going project)[b] makes us convinced that mobile apps have great potential in reaching out to rural illiterate farmers.	-Many rural communities in Northern Ghana do not have access to internet to use online mobile apps. -Many farmers in Northern Ghana do not own smartphones. -Many of the farmers are ICT phobia largely because of language and literacy barrier.
Conventional phone services	-High penetration of mobile phones in rural Ghana. Farmers already use phones for calls . -Existing phone services such as pre-recorded audio phone messages for illiterate farmers and SMS to literate farmers are currently operated in Northern Ghana e.g. FARM Radio and ESOKO. This allows for integration of hydroclimatic information services into those existing services and business models, which may add to sustainability of research output.	-Most existing phone-based services are not free and this raises the issue of information asymmetry where only higher-income farmer groups can afford and access hydro-climatic information. -SMS-message fatigue is occurring among literate farmers as the cheapest phone services come with advertisement-messages

Website	- Websites that provides climatic information services exist in Ghana (GMET,2016) - They are rather quick to develop and supports some level of interactions.	-Web-based services often face the challenge of sustaining users to visit on a frequent basis. -They offer limited opportunity for interactions -Limited internet access is also a major challenge in many rural communities. -Farmers will find it difficult to read and interpret information
Other non-ICT models[c]	-Non-ICT media are effective as farmers are able to have a face-to-face interaction with information providers where demonstrations are carried out for better understanding of concepts. -Non-ICT models include formal and informal periodic meetings where farmers interact and pass on relevant information to each other within both the irrigation scheme and communities. -Mobile Vans from Information Services Department readily provide information to farmers in communities.	themselves because of limited literacy -These models are not responsive enough for daily hydro-climatic information exchange. -Data providers do not have direct interaction with users and information transfer may take several days when moving vans are used. - Moving vans do not create a platform for questions or further clarifications and farmers may miss relevant information. -Female farmers are mostly not invited to attend such meetings and on few occasions when they are present, they are unable to express their opinion because of the male dominant conversation. -Farmers held sentiments and affluence may also play a role in making it more difficult for information access.

[a] http://gcrn.org.gh/dev/?p=251.

[b] https://uclexcites.wordpress.com/2018/05/01/the-role-of-sapelli-in-collecting-indigenous-weather-climate-forecast-data/.

[c]Non-ICT models include formal and informal periodic meetings where farmers interact and pass on relevant information to each other where information provider is often the irrigation water manager, head of farmer organization and extension officers. Another model is moving vans from the ministries and departments uses megaphones for loud announcements vital for farmers use.

2.5 Discussions

This study set out with the aim of diagnosing how socio-ecological settings of rice farmers in northern Ghana could affect the design and operationalisation of a hydro-climatic EVO. In this section, we draw on the insights from our diagnostic analysis to outline the characteristics of our hydro-climatic EVO. The design aims to overcome the identified challenges and capitalize on opportunities identified in section 2.5.2. The framework consists of two main parts: the structural elements of the framework and the processes through which it operates. We discuss the process of designing the EVO through the lens of the four dimensions of RI.

2.5.1 Design features: description of the structural elements

Our diagnostics resulted in different hydro-climatic information needs, challenges and opportunities for an EVO. We propose a hydroclimatic EVO (Fig. 2.4) consisting of three major elements; (i) data sources, (ii) data handling processes, (iii) platform for information and data exchange.

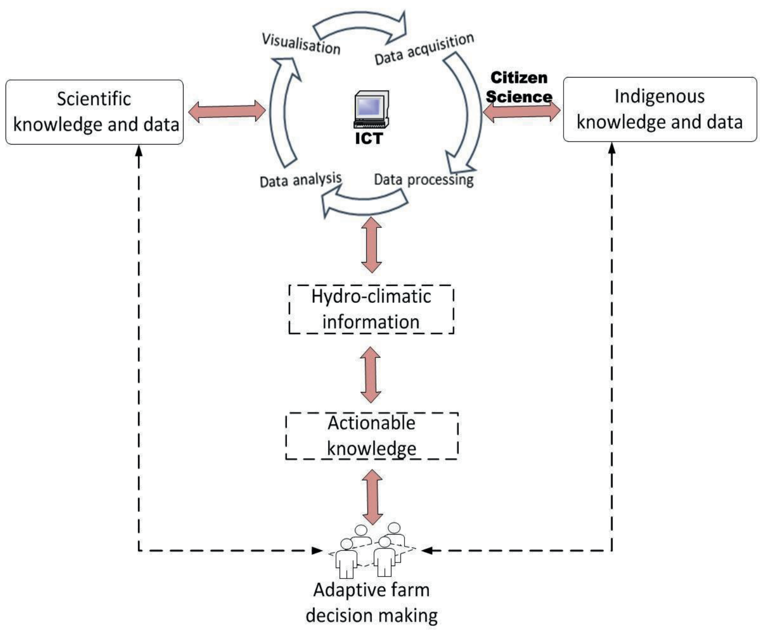


Figure 2.4: Fundamental Architecture of hydro-climatic EVO

(i) Data sources

Data will be sourced from two main knowledge systems; indigenous and scientific knowledge systems (see Fig. 4). As explained earlier, Ghanaian farmers use indigenous ecological knowledge to understand weather and climate patterns in order to make decisions about crop and irrigation cycles (Nyantakyi-Frimpong, 2013). Prior to every season the EVO will collect farmers' seasonal forecast of rainfall onset and cessation date and, rainfall amount and degree of temperature forecast expressed on a nominal scale of below, normal or above normal. Also within the season, the EVO will collect farmers' twenty- four (24) hours weather forecast of low, medium or high rain.

Second, seasonal temperature and rainfall data from European Centre for Medium Range Weather Forecasts (ECMWF-S4) seasonal forecasts system 4 (Molteni et al., 2011) will be analysed to also provide same seasonal climate information on rainfall onset and cessation date, amount of rainfall and degree of temperature also expressed in a nominal scale of below, normal and above normal. ECMWF-S4 is a state-of-the-art seasonal ensemble climate model that provides seasonal climate forecast on daily timescale into seven months ahead of time. The daily nature of the data will allow us to estimate daily rainfall amount of either low, medium and high.

(ii) Data handling and processing

The second element of the framework is the data handling process where indigenous and scientific data are collected, processed, analysed, and visualized. The collection of data will be partly automated. The hydro-climatic-EVO will offer a platform where farmers can regularly upload their seasonal climate and daily weather forecast information. These indigenous forecast information from farmers will be complemented with those from scientific forecast.

There are clear differences and limitations of both data sources. However, seasonal information such as rainfall onset and cessation date, above, below and normal rainfall generated from the analysis of the ECMWF-S4 temperature and rainfall data will be used to complement those predicted by farmers using their indigenous knowledge. In a similar way daily weather information such as low, medium and high rainfall predicted by farmers will complement information estimated from the daily data from ECMWF-S4 or any other weather model. There is potentially great value in combining both sources of data. For example, both data sources have inherent value that will complement the weakness exhibited by each without substituting one for the other and building on their respective strengths. The question that remains is whether information from both sources will be provided independently or combined. Developing a comprehensive approach to either independently present scientific and indigenous forecast information or harmonize them for actionability remained to be further explored in our next study.

(iii) Information exchange for adaptive farm decision-making

The hydro-climatic EVO has additional features that distinguish it from other EVOs. It offers a participatory opportunity to actively engage end-users to co-create actionable knowledge. Farmers can share their forecast information and receive tangible information for their adaptive farm decision-making. For example seasonal climate information such as onset and cessation date, rainfall amount (be it above, normal or below normal) and seasonal dam water levels, and the degree of temperature per season will support:

(i) Pre-season decisions: such as when to buy seeds and which variety to buy, irrigation land size allocation and Labour size, which weedicide, pesticide and fertilizer to buy.
(ii) Land preparation decisions: when to clear land, when to harrow and plough,
(iii) Planting decisions: when to nurse, transplant and which planting method to adopt and
(iv) Harvesting decision: when to harvest and by which method.

On the other hand daily weather information (be it yes/no rain, low, medium or high rainfall) received by farmers will support farm decisions such as

(i) When to fertilize,
(ii) When to apply weedicides and pesticides and
(iii) When to carry out supplementary irrigation.

Details of information need and decision-making by rice farmers are discussed by Nyamekye et al. (2018) and Nyadzi et al. (2018). The EVO offers tailor made information that generate actionable knowledge to for decision making at different stages of farming. The interface of the Hydro-climatic EVO will be carefully designed with close collaboration with end-users to ensure effective data and information exchange with a particular focus on non-literate users with little or no prior ICT experience. The hydro-climatic EVO therefore envisages opportunities for learning and becoming an integral part of rice production systems in the region.

2.5.2 Hydro-climatic EVO: addressing challenges in existing information systems

The main challenges of existing information systems and what our EVO seek to do differently is summarized in Table 4. Challenges with existing systems that limit their usefulness include user unfriendliness of the system, inaccuracies of forecast information, relevance of information, managing user expectation and weak collaborations.

2.5.2.1 Design process: hydro-climatic EVO as responsible innovation

We build on the responsible innovation framework (Stilgoe et al., 2013) to assess the initial steps taken in the process of building a hydroclimatic EVO, and to identify the challenges ahead. For each cardinal principle, we raised some salient questions that seek to guide the development and implementation.

(i) Anticipation

Anticipation involves "systematic thinking aimed at increasing resilience, while revealing new opportunities for innovation and the shaping of agendas for socially-robust risk research" (Stilgoe et al., 2013). This relates to forecasting, and imagining possible and desirable futures, but also to the 'ethics of promising'. This dimension of the RI framework makes us ask 'what if…?' questions (Ravetz, 1997) to expose the various contingencies associated with the development of the hydro-climatic-EVO. From its conception, the envisaged hydro-climatic EVO anticipates the future by considering the potential impacts of climate variability and change on farmers' daily and seasonal farm decision making. Rather than optimizing for the most likely future scenario, the hydro-climatic-EVO accounts for the associated uncertainty by trying to make variability in water availability manageable for different farming purposes. Climate variability and change is only one of the potentially relevant future developments. Equally important is the unintended consequences which could be the future development of farming in the region, in terms of economic prospects and farmers' aspirations. Will farmers move out of agriculture into other occupations if possible, or do they see a future for themselves and their children that will motivate them to further improve their farmer system and embrace new technologies such as an EVO? The approach taken to ensure inclusiveness through user-centered design (see below) creates some challenges for the 'ethics' of promising. Developing features that are most relevant to users implies that these may be quite specific and/or novel, making it uncertain to what degree the innovation will be able to deliver on the promised usefulness of the EVO.

(ii) Reflexivity

Reflexivity means "holding a mirror up to one's own activities, commitments and assumptions, being aware of the limits of knowledge and being mindful that a particular framing of an issue may not be universally held" (Stilgoe et al., 2013). It is about questioning the value systems and theories that shape science, innovation and their governance. The envisaged hydro-climatic-EVO will be developed through interdisciplinary collaboration, where the absence of shared standard ways of operating leads to mutual questioning and thus some form of reflexivity. This reflexivity prevents the natural scientists to retreat into sole modelling, and prevents the social scientists to retreat into sole analysis of social processes. Reflexivity also requires carefulness not to violate the social and cultural ethics of the society in which the project is carried out, particularly because different countries and vulnerable populations are involved. This was vital especially during our interaction with farmers, for example regarding their traditional knowledge and regular engagement for information exchange. A continuous challenge is to remain reflexive about assumptions made in building the EVO, and to what extent these are aligned with the users' context. Thus the need for continuous scrutiny of project activities and dealing with every farmer and situation distinctively.

(iii) Inclusion

The user-centered design framework (Zulkafli et al., 2017) adopted for the development of the hydro-climatic EVO strongly emphasizes inclusion. Various actors and institutions were actively involved in the early development process, with particular attention paid to potential end-users. The engagement of different actors on the project especially during regular workshops and trainings is expected to play a pivotal role in creating a sense of ownership among the farmers and other actors (public and private sector agencies, local leaders and chiefs). A clear example of inclusiveness is the involvement of both rainfed and irrigated rice farmers on the project. Each of these farmer types has its own need, which must be met. Also the reliance on both scientific and indigenous data and knowledge systems to generate actionable knowledge enhances the inclusiveness of hydro-climatic EVO. Inclusion is never perfect, however, and pragmatic choices have an impact. The particular study area receives considerable attention from development actors, partly because of its proximity to the city of Tamale and its university. Farmers with higher literacy levels, fluency in English, and familiarity with ICT are easier to involve in e.g. local smartphone-based data gathering.

(iv) Responsiveness

Responsiveness is the capacity to "change shape or direction in response to stakeholders, public values, and changing circumstances" (Stilgoe et al., 2013). Funded by a university programme (INREF[1]) that values "research for development", our hydro-climatic-EVO project has a good starting point for achieving responsiveness. The user-centered design approach to developing the EVO emphasizes the importance of the user context as a starting point in terms of livelihoods, culture and decision-making. A choice that was made early in the project to include the practice of rainfed farming as well as

[1] See http://www.wur.nl/en/Research-Results/Projects-and-programmes/ INREF.htm

irrigated farming, was responsive to the importance of rainfed farming for large parts of the rural population, in particular the poorer sectors. The design and structure of the hydro-climatic-EVO aims to meet the needs of users and remain flexible enough to respond to future changes in circumstances, e.g. new knowledge and emerging perspectives, new technical possibilities or demands, as well as changes in livelihoods or cultural values. Being a university-led project with a limited period (5 years) creates some challenges for responsiveness as well. What about responding to changes when paid project members are no longer around? Finally, the responsiveness to stakeholder and public values might be challenged by the responsiveness to academic values and incentives, which prioritize modelling, analysis and publication over stakeholder engagement and practical application. This limitation is therefore recognized and in cases where they emerged efforts must be put in place to amicably deal with them. For example, we seek to understand indigenous forecast techniques and develop methods to quantify them in order to harmonize them with scientific forecast derived from models.

2.6 Conclusion

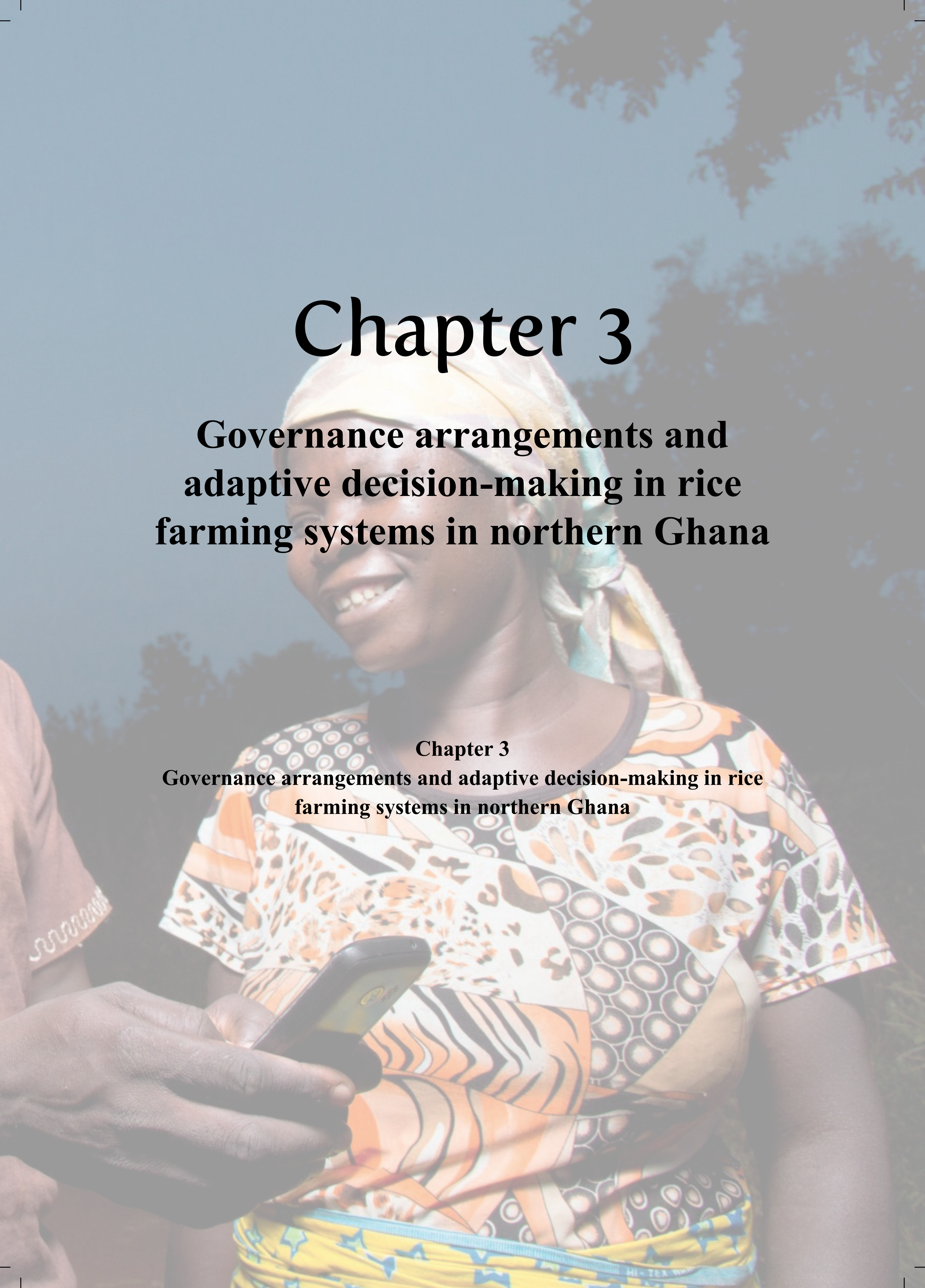
The diagnostics study presented here offers a number of important insights that help to further refine and implement the hydro-climatic EVO. First, participatory design will create a sense of ownership among farmers. This is because, being actively involved from the design to production and implementation stages of the project is novel, and it increases the likelihood that the hydro-climatic information services developed will be useful for farmers. Secondly, the diagnostics provides in-depth appreciation of the socio-ecological conditions in which the EVO will operate. Thirdly, our reflection using the RI framework exposed key challenges, which the hydro-climatic EVO development process needs to deal with. Asking these questions, however, allowed us to discuss plausible solutions at an early stage in the design process.

One of the key challenge anticipated is the reliance on stakeholder participation throughout the project cycle. Farmers need incentives and motivation for continuous participation. In our case, we argue that both rainfed and irrigated farmers are challenged by climate variability and limited water availability and that urgent action is needed. The information services developed can help with improving their farm decision making in order to better cope with climate variability. However, it remains unclear how much time future users and other stakeholders are prepared to devote to the design process. Close monitoring is needed to find out if farmers feel that providing regular data and information is too time consuming. Limited commitment of users can potentially reduce data availability and quality. As a response we pay specific attention to openness and transparency in the design process, to allow participants to freely share their opinions and concerns. At the same time, researchers need to be proactive. They should be seen as and perceived to be serious with the process through their active engagement. In the context of decision-making, our reflections and findings present key challenges in terms of language, interpretation and usability. The knowledge co-creation and subsequent provision of actionable knowledge must align with literacy and user confidence in being able to easily relate to outputs.

Our approach and innovation possesses the potential to deal with the socio-ecological challenges imposed by climate variability and limited water availability. We argue that one of the most important drivers of success to our project will be the intensive collective interaction of scientist and farmers compelled by the structure and mechanism of the hydro-climatic EVO, in which scientist and other stakeholders think, plan and execute together from common ground. In addition, the responsible line of questioning will reduce the possible surprises and eventualities that may affect the EVO development. Important issues to follow-up on are the performance of indigenous and scientific forecast to meet the hydro-climatic information needs of rice farmers in Northern Ghana. Another issue from our diagnostics is how governance systems limit information flow and interpretation. For our follow up studies we aim to investigate governance arrangements and how these are enabling or inhibiting adaptive decision-making amongst farmers and water managers. Also in the next stage of this project is to find out what is the most preferred model of information exchange by rice farmers. The potential of including farmers in information collection through citizen science potentially bridges part of the gap between scientific and indigenous expertise and constitutes a novel contribution to the field of environmental observations.

We conclude that the socio-ecological conditions in Northern Ghana necessitate the development of an effective second generation hydroclimatic EVO as this potentially responds to the principles of RI expected to drive technological innovation to manage change in natural resource management. Finally, the proposed hydro-climatic EVO has potential for influencing adaptive farm decision making in Northern Ghana in spite of identifiable challenges. Using the RI framework has helped us to refine these challenges and offer concrete suggestions to improve both the design and implementation of the proposed platform in a responsible way.

Acknowledgements
We acknowledge the support of the EVOCA programme and research. We also thank the management of the Bontanga Irrigation Scheme and farmers for partaking in the study.



Chapter 3

Governance arrangements and adaptive decision-making in rice farming systems in northern Ghana

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Governance arrangements and adaptive decision-making in rice farming systems in northern Ghana

Abstract

Climate variability has consequences on water availability in rice farming systems. In Ghana, rice farmers in the Northern Savannah are amongst the most vulnerable to long periods of drought and erratic rainfall conditions. Within the Kumbungu district, farmers engaged in both rain-fed and irrigated rice farming are no exception. Coping with uncertain water availability conditions requires adaptive decision-making for sustained productivity in rice cropping. From an adaptive governance perspective, the extent to which formal and traditional governance arrangements enable adaptive decisions amongst rice farmers remains a key question. Using an exploratory research design, the study investigates three key questions; what water-dependent decisions rice farmers take and how these are adaptive to changing water availability conditions; what formal and informal governance arrangements rice cropping decisions are embedded in; and how existing governance arrangements enable or constrain adaptive decision-making. Rice farmers in twelve communities around the Bontanga Irrigation Scheme in the Kumbungu District in the Northern region were engaged through individual interviews and focus group discussions. The study reveals that farmers take six major water-dependent decisions throughout the cropping season; decision to or not to plant rice, land preparation, planting, weed control, fertilizer application and harvesting. Farmer decisions are most adaptive to water availability conditions during planting and fertilizer application. Both formal and traditional governance arrangements influence the extent to which farmers are able to adapt to changes in water availability conditions. The paper also reflects on the potential of hydro-climatic information and the place of Environmental Virtual Observatories (EVOs) in adaptive governance and decision-making.

Published as: Nyamekye, A. B., Dewulf, A., Van Slobbe, E., Termeer, K., & Pinto, C. (2018). Governance arrangements and adaptive decision-making in rice farming systems in Northern Ghana. *NJAS-Wageningen Journal of Life Sciences*, *86*, 39-50.

3.1 Introduction

Climate variability has significant impact on food systems especially in developing countries posing challenges in decision-making due to fluctuations in temperature and precipitation levels (Pietrapertosa, Khokhlov, Salvia, & Cosmi, 2018; Chaffin et al., 2016; Bhave, Conway, Dessai, & Stainforth, 2016); Buhaug, Benjaminsen, Sjaastad, & Theisen, 2015). In Northern Ghana, meeting water needs in rice production remains a major challenge amongst rice farmers. This is attributable to highly variable and often unfavourable climatic conditions, dry spells and a mix of technical deficiencies of know-how, farm machinery and institutional inefficiencies in both irrigated and rain-fed rice farming systems (Adongo, Abagale, & Kranjac-Berisavljevic, 2015; Kranjac-Berisavljevic et al., 2003). The Northern region has a single farming window typical of the Savannah belt in Ghana (Bawayelaazaa Nyuor et al., 2016; Yaro, 2013; Nantui, Bruce, & Yaw, 2012; Donkoh & Awuni, 2011). Model projections suggest worsening climatic conditions with anticipated adverse impact on water availability (Asante & Amuakwa-Mensah, 2015; Yaro, 2013; Laube, Schraven, & Awo, 2012; Quaye, 2008) and land degradation amongst others.

Interventions by government and private actors have sought to improve water availability conditions. This has come with infrastructure development and the mechanization of farming. Such infrastructure include irrigation schemes constructed to support small scale farmers who currently dominate farming systems in Northern Ghana. The Bontanga Irrigation Scheme in the Kumbungu district, North-East of the city of Tamale, is one of such schemes constructed by government in Northern Ghana. The scheme being the largest in northern Ghana covers a land area of 570ha and gravitationally distributes water unto farmlands within the scheme (Braimah et al., 2014). The scheme serves about 14 immediate communities with farmers from these communities owning and cultivating varying hectares. Main crops cultivated include rice, pepper, onion, tomato and okro. The scheme is regulated by the Ghana Irrigation Development Authority with the mandate of developing irrigation infrastructure to improve water and soil conservation practices.

Not all rice farmers in the Kumbungu district have access to the irrigation system, and those who do often cultivate rice outside the irrigation system as well. Water availability is a key concern for rice farmers, affecting numerous decisions throughout the cropping cycle. Increasing uncertainty about water availability conditions requires rice farmers to be adaptive in their decision-making by anticipating or responding to early or late onset of the rainy season, erratic rainfall, dry spells or excessive rainfall. Although rice farmers have the final responsibility to make rice cropping decisions, these decisions are embedded in broader set of decisions by other farmers and other actors, as part of both formal and traditional governance arrangements. The extent to which these governance arrangements enable adaptive decision-making is considerably under-studied.

The study addresses the overall question "How do rice farmers adapt their decisions to variability and uncertainties in water availability, and how are these decisions embedded in broader governance arrangements? The results section of this paper is divided into three parts with each part responding to a specific question. The first part is descriptive and addresses the question "which water-dependent decisions do rice farmers take and to what extent are these adaptive to changing water availability conditions?" Here, we identify key decisions and adaptive actions to manage water challenges. The second part probes into governance arrangements and establishes the tangle with decision-making by posing the question "what are the formal and informal governance arrangements in which rice farming decisions are embedded?'. The third part launches an inquiry into the governance arrangements-adaptive decision-making interconnection by posing the question "how do these governance arrangements enable or constrain adaptive decision-making in rice production systems?'. Following the answering of research questions, we further reflect on the potential of hydro-climatic information and Environmental Virtual Observatories (EVOs) in supporting adaptive decision-making and governance of rice production systems.

3.2 Theoretical framework

Adaptive governance has been cited as a guiding theory for understanding the dynamics of social-ecological systems and how these can be accounted for in governance arrangements and decision-making processes (Rijke et al., 2012; Termeer et al., 2011; Olsson et al., 2006). Karpouzoglou et al. (2016b) highlight the strength of adaptive governance as a theoretical lens as it integrates governance dimensions of adaptive capacity, collaboration, scaling, knowledge and learning. Thus, the capacities of social-ecological systems to respond and manage uncertain conditions could be better explored. Adaptive governance further allows for the engagement of both formal and informal institutions and cross-scale interactions (Gunderson, Cosens, & Garmestani, 2016). The concept has been defined in numerous ways. Dietz et al. (2003) coined the term adaptive governance in their paper on "the struggle to govern the commons". They define adaptive governance as "managing diverse human-environmental interactions in the face of extreme uncertainty". Walker et al. (2004, p. 8) present adaptive governance as "the process of creating adaptability and transformability in socio-ecological systems". Gunderson et al. (2016) define adaptive governance as the set of institutions and frameworks that facilitate and foster adaptive management. In agreeing, Green et al. (2013) posit that adaptive governance is one way of bridging the dichotomy between legal structures that assume away uncertainty and adaptive management that focuses on acknowledging and winnowing uncertainty. In borrowing from Plummer and Armitage (2007), and Folke et al. (2005), Munaretto et al. (2014) refer to adaptive governance as "a continuous problem-solving process by which institutional arrangements and ecological knowledge are tested and revised in a dynamic, ongoing, self-organized process of learning by doing".

Termeer et al. (2011, p. 161) define a governance arrangement as "the ensemble of rules, processes, and instruments that structure the interactions between public and or private entities to realize collective goals for a specific domain or issue". They thus acknowledge the importance of accounting for both private and public actors, and their interactions. We define formal governance arrangements as "instruments and processes established by laws and treaties which are documented to be adopted as operational conditions in a given setting". Traditional governance arrangements on the other hand as "culturally defined and sometimes undocumented rules and ways of behaviour integral in the social fabric of a people" (Termeer, Drimie, Ingram, Pereira, & Whittingham, 2018; Chen & Zhu, 2015; Worden, 2010).

Another key concept for our analysis is adaptive decision-making (Chater & Oaksford, 2000; Weber & Johnson, 2009). That adaptive governance arrangements will ultimately result in decisions that are adaptive to uncertain changes is often assumed but rarely studied. As different from the broader concept of adaptive governance, there is no readily available conceptualization of adaptive decision-making that we can rely on for our purposes. In essence, decision-making is about making choices between different decision options. The question here is to what extent the options chosen respond to observed or anticipated environmental conditions. The more variability and uncertainty in relevant environmental conditions, the stronger the need for decisions to be adaptive. We build on Robert et al. (2016, p. 2), who define adaptation in farm decision-making as "adjustments in agricultural systems in response to actual or expected stimuli through changes in practices, processes, and structures and their effects or impacts on moderating potential modifications and benefitting from new opportunities".

To make the distinction between regular decision-making and adaptive decision-making, we will rely on the following operationalization. We understand regular decision-making as choosing standard decision options, based on generalized expectations of what to do under normal circumstances, but independent of the observed or anticipated environmental conditions that present themselves. In contrast, we understand adaptive decision-making as choosing non-standard decision options, in response to circumstances that are considered abnormal or unexpected (Phillips, 1997). Thus, the decision-making process is perceived as a succession of decisions to be made, which can be more or less adaptive to changing circumstances.

The provision of relevant and timely information about observed and anticipated environmental conditions has the capacity to reduce risks and uncertainty in farmer decision-making (Lundstrom & Lindblom, 2018;

Clarke et al., 2017). Information systems or observatories creating networks and enabling knowledge exchange amongst key actors in farming systems have also been central in discourse on improving farmer adaptation (Nie & Schultz, 2012). We thus reflect on the place of Environmental Virtual Observatories (EVOs) as discussed in Karpouzoglou et al. (2016a). They use the terminology to describe a suite of information gathering, processing and dissemination technologies supported by World Wide Web that facilitate cross-fertilization of various sources of knowledge on shared virtual platforms. The theoretical framework of the study is graphically presented in Figure 3.1.

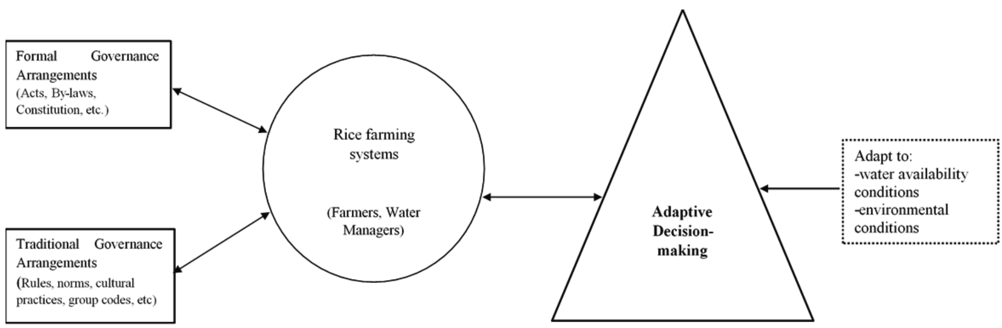

Figure 3.1: Theoretical framework of the study.

3.3 Materials and methods

3.3.1 Case study

A case study research design (Baxter & Jack, 2008; Stake, 2008) was adopted in conducting the study in Ghana. The study was undertaken in communities around the irrigation scheme in the Kumbungu district in Northern Ghana. The district is home to about 34,341 people with farming as a major economic activity. The Kumbungu district was carved out of the then Tolon-Kumbungu district in the year 2012. The irrigation scheme lies between latitude 9^0 30" and 9^0 35"N and longitude 1^0 20" and 1^0 04"W and covers an area of 570ha. A total of sixteen farming communities were selected from upstream, mid-stream and downstream of the Bontanga dam. These include Bontanga, Wuba, Saakuba, Yiepelgu, Dalung, Voggu, Tibung, Kushibo, Kpalsegu, Zangbalun, Kumbungu, Gbugli, Kpalgu, Kpegu-Biegu, Kpegu-Bagurugu and Kpegu-Piegu. The study area is graphically presented in Figure 3.2.

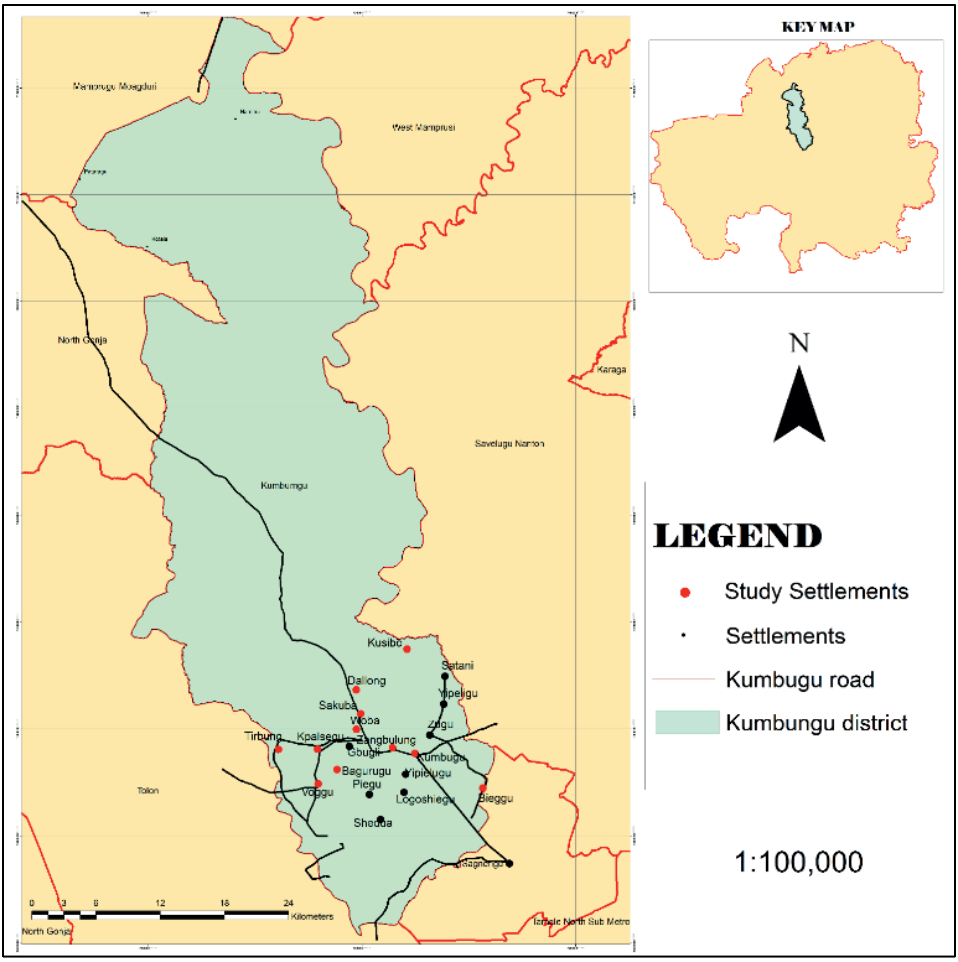

Figure 3.2: Map showing study communities in the Kumbungu district

3.3.2 Data collection

The study through an exploratory approach uses qualitative methods to explore context specific conditions addressing research questions (Taylor, Bogdan, & DeVault, 2015; Patton, 2005; Denzin & Lincoln, 2008). Study communities were sampled purposively (Etikan, Musa, & Alkassim, 2016; Devers & Frankel, 2000). Within each zone, 15 farmers practising either rainfed rice farming only, irrigation rice farming only or both were purposively chosen and interviewed. In addressing the first specific research question, farmers were interviewed using unstructured interview guides (see appendix 3a) (Ruane, 2011; Schensul, Schensul, & LeCompte, 1999) for an average of 35 minutes. Farmers were mostly interviewed in their homes and farms (in a few cases). Questions centred on regular decisions farmers take, adaptive actions pursued in water management and the extent to which these were effective under changing conditions. Furthermore, Focus Group Discussions (FGDs) were organized with groups of an average size of 12 farmers in each community (see appendix 3b) (Kothari, 2004; Stewart & Shamdasani, 1998). These served as avenues to further interrogate feedback received from direct interviews with farmers. Leaders of farmer groups, female and male farmers made up Focus Groups. FGDs were held at convenient meeting points where most farmers convey during leisure. Discussions allowed for brainstorming and an understanding of how governance arrangements influenced adaptive decision-making.

In probing into existing governance arrangements, farmers and water managers as part of interviews responded to questions on what governance arrangements were identifiable in communities and within the irrigation scheme (see appendix 3c). Rain fed rice farmers operated within the boundaries of traditional governance arrangements (Nchanji, 2017) whereas irrigated rice farmers had their activities framed around formal arrangements defined by the Ghana Irrigation Development Authority and the Ministry of Agriculture. As part of FGDs, farmers were engaged on what these governance arrangements are and how these influenced their operations. Chiefs, opinion leaders and local government representatives were also engaged. A document analyses was also undertaken to establish meaning from frameworks received from related authorities.

The third level of engagement revolved around how governance arrangements enabled or constrained adaptive decision-making. This enabled framing of the challenge of adaptive decision-making and formed an integral part of questions posed both during direct interviews and FGDs. A summary of the research methodology is presented in Table 3.1.

Table 3.1: Research methodology

Research question	Research methodology	Sampling method	Research instrument	Data collected	Data analysis
Question 1: Decision-making	Individual farmer/water manager interviews	Purposive sampling	Interview guide	-Types of decisions -Adaptive actions -Outcomes of adaptive actions	-Transcription of recordings -Editing of field notes -Content analysis
	Group engagement	Purposive sampling	Focus group discussions	-Types of decisions -Adaptive actions	
Question 2: Governance arrangement	Document analysis	Purposive sampling	Interview guide	-Arrangements on water management -Guidelines for decision-making and communication	-Definition of document types -Content analysis
	Individual farmer/water manager interviews	Purposive sampling	Interview guide	-Traditional arrangements on water management -Rules of community engagement -Leadership and decision-making -Norms on farming and water management	-Transcription of recordings -Editing of field notes -Content analysis
	Group engagement	Purposive sampling	Focus group discussions		
Question 3: Correlation between governance arrangement and adaptive decision-making	Individual farmer interviews	Purposive sampling	Interview guide	-Outcomes of adaptive actions	-Transcription of recordings -Editing of field notes -Content analysis
	Group engagement	Purposive sampling	Focus group discussions	-Propositions on both traditional and formal governance arrangements	

3.3.3 Data analysis

Firstly, field notes were synthesised to deduce relevant responses given the research questions. Recordings from interviews and FGDs were transcribed using Microsoft Word. Transcriptions were further analysed under key themes through a content analysis using the atlas.ti programme. Identifiable themes include stakeholder role play, water management practices, decision types, adaptive practices, formal governance arrangements, and traditional governance arrangements amongst others. Data was further synthesised to establish correlation between themes and for presentation.

3.4 Results

3.4.1 What decisions do rice farmers take in the Bontanga area?

Farmers take six major decisions in the cropping cycle; decisions on *whether to engage in rice farming*, *land preparation, planting, weed control, fertilizer application* and *harvesting* (see Figure 3.3). These are regular decisions taken by farmers irrespective of the rice farming system being practiced and the varying conditions under which they operate. The sensitivity to water availability conditions can also be observed.

3.4.1.1 Rain-fed rice farming systems

Decision-making is an intra-household activity with men initiating and directing the process. Women and children almost readily respect and respond to the call to duty on the farm by the household head. The period between May-October within the year is of significance to rain-fed rice farming households as it is the only cropping time after which households are unable to engage in food production due to dry conditions.

The first key decision is whether or not to cultivate rice. For some households, this decision is the sole prerogative of the head (in most cases male) of the household. In some contexts, the head and spouse (or spouses if polygamous) discuss privately and communicate to the rest of the family. Rice is cultivated as a commercial crop thus, the decision is strategic and requires allaying all fears and risks the household envisions to be faced with, especially how to manage water needs on the farm. Household heads also consult other rice farmers in their communities in their outlook of the previous season and assessment of the prospects of the current season (see box 1). Experiential and traditional knowledge play a key role at this point. Rainfall patterns and soil moisture content significantly determine decision outcomes at this point.

> **Box 1**: **Decision-making amongst rice farmers**
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> *"Before the season begins, rice farmers engage in dialogue to discuss expectations. Discussions revolve around water availability, access to seeds, farm machinery and fertilizer. We estimate the risk we have to face in the season by sharing our experiences, observations and information received. -Anonymous (Rain-fed farmer in Kpegu-Piegu community).*
>
> *"Most of the farmers cultivating rice in Dalung community are engaged in both rain-fed and irrigated rice farming. Our meetings are usually unstructured and could begin with few farmers sitting around. We spend more time together on Fridays after prayers at the mosque discussing challenges over the season with other farmers"-Anonymous (Rain-fed rice farmer in Dalung Community).*

In the case where the farmer decides to cultivate rice, the next key decision is when to prepare the land. Rainfall levels and soil moisture content could influence the land clearance method adopted. Land is usually prepared when soil moisture content is high or estimated to be sufficient. Land preparation under regular conditions is usually done between April-May (see also Laube et al., 2012 for similar findings) using simple tools such as machetes and/or hoes, bullock-powered ploughs or tractors dependent on economic and physical factors. In Yielpegu, Zangbalun and Kpegu-biegu, some farmers own bullock-powered carts which they use for land clearance and ploughing on their farms. Owners of the aforementioned also render rental services to other farmers within and around their communities. Farmers pay for services in kind (2 bags of rice) or an equivalent in cash. In Kumbungu, Bontanga and Wuba, farmers pay between 200 and 450 Ghana cedis to engage tractor services for land clearance. An acre of land is averagely cleared in a day, two days or four days using a tractor, bullock-powered cart or simple hand tools respectively. Farmers' ability to pay is no guarantee of access to services. Some farmers engage tractor services outside the district at a higher cost. Where necessary, some farmers are selected or volunteer to scout for tractor services for their communities.

Farmers proceed to plant after the aforementioned activities have been completed. Planting is usually done in July when there is enough rainfall but earlier should the rains set in in June. Farm inputs such as labour, seed and water (soil moisture) are key pointers informing planting times. Seeds are planted directly through dibbering[2], broadcasting, or nursed and transplanted after a given period.

Weed is controlled in a single or double phase dependent on farmers' financial capacity. Pre-emergent weedicides are applied right after planting to control existing weeds. Post emergent weedicides are applied after rice begin to sprout. An average of two bottles of weedicides are applied on an acre of land by the farmer with the aid of family members.

The fifth major decision is on the application of fertilizer. Fertilizer is applied in early August but delayed when rains are erratic. Farmers obtain fertilizers from agro-chemical shops mostly in Kumbungu or Tamale. Fertilizers are applied when seeds sprout and also when the rice plant is observed to tassel. Fertilizers applied include NPK and manure from animal droppings. About two bags of fertilizer is applied at a time on an acre of rice farm. Soil moisture content or rainfall patterns are important drivers. In some cases, although farmers could afford a second phase of fertilizer application, low soil moisture content and erratic rainfall become barriers to undertaking the activity.

The last decision is on the harvest of rice. The activity is undertaken between the September and October. Most farmers engage labourers to augment efforts by the household in harvesting rice manually. Some farmers also engage the services of combine harvesters. Rice is then partially boiled or

[2] A dibber is a pointed wooden stick for punching holes in the ground.

directly milled after and bagged for sale. Critical factors informing decisions on harvesting include market conditions, financial capacity, and estimated output from the farm.

3.4.2 Irrigated rice farming systems

Decision-making at the scheme level is led by the scheme manager guided by regulations of the Ghana Irrigation Development Authority. The guidelines establishing the scheme present it as a semi-autonomous entity thereby giving the manager the right to spearhead actions and day-to-day decisions at the local level. Instructions from the regional and national offices of the authority are however binding and considered in decision-making.

Periodic meetings are held at the beginning of the year to discuss operations under the scheme. Plans are designed under the leadership of the scheme manager with the support of farmers on water use, maintenance of laterals and effective farm management practices. Consultations are also initiated with external experts such as the MSD, ISD, and District Assembly amongst others. Nevertheless, the scheme manager has power to decide on what volumes of water to be discharged unto farmlands. Block and lateral leaders are under the instruction of the water manager on the quantities of water to be discharged at any given point in time. Farmers within the scheme have to decide on whether or not to plant rice in the year. Here, risks are perceived to be lower than farming under the rain-fed system.

For most farmers, the decision to plant is dependent on whether they also engage in rice farming under rain-fed systems outside the scheme. Under such circumstances, resources are split to ensure production in and out of the scheme in the year. Most farmers within the scheme are able to cultivate rice all year round due to water availability. The dry season however comes with a challenge where low water levels affects water distribution to farmers whose lands are downstream. Irrigation charges and cost of renting lands within the scheme are also disincentives. In the case where farmers have the financial capacity to acquire land and ultimately secure land, the problem of water management is not enough disincentive to grow rice.

The next major decision is on land preparation. Farmers have access to power tillers from the irrigation authority and hence are less stressed in efforts to obtain machinery for land clearance. Furthermore, because lands are not left fallow for long due to all year round cultivation, farmers have little to clear on the land at any point in time. For farmers who are indigenes and live in communities around the scheme, farm labour required at this point is mostly provided by the household. Farmers who are non-indigenes and live outside the district hire labour from communities around the scheme when necessary.

The activity of planting is done using the broadcasting method or lines and pegs. In the case where pegs are used, farmers adopt the dibbering method and plant at intervals along the lines using pointed sticks/dibbers. Seeds are obtained from agro-chemical shops and in some cases through the leadership of the scheme where prospective buyers request for a particular variety to be cultivated. The decision to cultivate a particular variety however remains the sole prerogative of the farmer. Most farmers however opt for long term varieties as these are perceived to have higher yields when water is readily available for irrigation.

Weed control is done individually but in some cases in consultation with other farmers who share boundaries to avert identified diseases which have tendencies of spreading. Decisions on disease and weed control are sometimes discussed collectively at the scheme level when identified. In consultation with technical staff at the irrigation authority, farmer decisions at the farm level are also informed by inputs on the best practices of the day for weed and disease control. Farmers also benefit from technical advice as part of interventions such as the Ghana Commercial Agriculture Project (GCAP). Labour for weed control is provided by the household or hired. Both pre-emergent and post-emergent weedicides are applied dependent on farmers' financial capacities.

The decision on when and what type of fertilizer to apply on the farm is taken at the farm level. Fertilizers are applied through a process of sprinkling or strategic placement across the farmland. Fertilizer types used are mostly same as those applied under the rain-fed system.

The decision on harvesting is made by the farmer guided by pre-conditioned factors in instances where there are buyers with specific interests. The scheme manager in providing support to farmers also solicits for buyers who purchase rice in large quantities. Farmers thereby engage in collective actions and decision-making at this stage.

3.4.3 How adaptive are decisions to water availability conditions under both systems?

Water availability is integral for rice production. With uncertainties in rainfall patterns and weather conditions, farmers (especially under rain fed systems) have to adapt to conditions that could affect their productivity and output. From the study, it is evident that farmers at each decision point make choices aimed at managing water scarcity (see Figure 3). The outcomes of decision options and how these facilitate adaptive water management on the farm is fundamentally defined by both controllable and uncontrollable factors.

Hydro-climatic information and farmer experiential knowledge are key at this point. The absence of or inadequacy of long term information on variability in weather conditions is detrimental to productivity especially when yields from the previous season are low (see box 2). Farmers at each point have to be adaptive in their decision-making to maximize decision outcomes, learning and attainment of new knowledge where possible.

Box 2: Weather conditions and adaptive decision-making

"I relate the weather now to exactly what we experienced in the late 1970s. Rains have been erratic affecting my farming activities outside the scheme. The rains do not come in the month of May when I used to prepare my land. I have to wait till June or July after a few rains before preparing my land. This is a major challenge as I have no control over the rains and hence did not want to invest my limited profit into a possible failed harvest. I had to choose whether to cultivate rice, maize, raise livestock or support my wife with the money in her food vending business."- Anonymous (Rain-fed rice farmer in Gbugli Community).

"A sense of how the weather will be at the beginning of the season is all we need as we have no options on how to meet water needs on our farms. Although my land is near the irrigation scheme, I do not have the machinery required to pump water from the dam unto my farmland. I therefore look up to the gods for a good year. This poses a lot of uncertainties on the way forward for us as rice farmers."- Anonymous (Rain-fed rice farmer in Sakuuba Community).

Following the decision to cultivate rice, farmers have to deal with the challenge of preparing their lands at the 'right' time. Unpredictability of weather conditions and limited access to some farm inputs make it challenging. Under rain-fed systems, the decision to use tractor could come with the risk of high cost of service and longer waiting period to access tractor affect timely land clearance. Thus access to tractor translates into timely land clearance for the rains. For some farmers, a less expensive option will be to use bullock-powered carts which although not as quick as tractors are cost saving and timely as well. For other farmers manual labour is an option when land size is smaller. Under irrigated farming systems, the availability of water for irrigation presents less stress in adaptive decision-making. Irrespective of which method is used in land clearance, farmers are able to meet water needs on their farms. This however comes at a cost as farmers pay fees for irrigation services. However, methods that enable time saving could increase the chances of the farmer completing the season in good time.

Adaptive decision-making also involves choosing the type of seed variety to cultivate. Long term varieties are a better hedge against flooding. Maturity periods are however longer and present a risk of stunted growth and low harvest should the rains be erratic. Thus for most rain-fed rice farmers whose farms are more than 100 meters from the banks of the Bontanga river, planting short term varieties[3] is a more adaptive option. Majority of short term varieties have higher market value thus an adaptive step could be to face the risk of water scarcity and aim at higher returns on sale of produce.

On planting, the broadcasting or dibbering method is least time consuming and best method when planting is delayed or rainy days have been missed. Both activities are time consuming and could slow adaptation to rainfall conditions. Broadcasting is common amongst rain-fed rice farmers considering low financial and labour capital requirements. However, farmers face difficulty in applying fertilizer in due time. Nursing and subsequent

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[3] Varieties include AGRA, Moses and Jasmine

transplanting is best when preparations are started early and projected rainfall will be high.

Farmers during weedicide application consider soil moisture content after sowing. Pre-emergent weedicides are applied at least 7 days after sowing in case soil moisture content is high and post emergent weedicides after seeds sprout. Weedicides in some contexts are not applied at all due to delayed rains and sprouting and thus an anticipated failed harvest. For farmers who cultivated lands both in and out of the scheme in the season, weedicides are channelled only to land cultivated inside the scheme. The post weedicide application period is where most farmers lament and hence deem it as the 'tipping point' of the season. This is as a result of the inability of farmers to control conditions on the farm after this point. Thus, unfavourable conditions with regards to water availability is a recipe for disaster and a sign of a possible failed harvest at the end of the year.

Adapting to water scarcity requires a consideration of decision outcomes during fertilizer application. The first option is to apply compost within 2 weeks after planting. Soil moisture content must be high to improve the assimilation of fertilizer by the crop. This nevertheless does not guarantee higher yields hence the need to apply a second fertilizer (Ammonia) within 25 days after planting under good water conditions. For some farmers, risks associated with water is so high and hence not worth it applying fertilizer at all[4] as low or no rains result in failed harvests.

Expected outcomes at harvest time is a bountiful harvest. Water scarcity is not an immediate consideration during harvest time. Farmers consider using combine harvesters or manual labour for harvesting. Given the fact that preceding conditions such as water availability and soil fertility have direct impact on yields, adopting the most effective method in harvesting to reduce losses is a pre-requisite. Generally, the harvest from most rain-fed rice farms in 2016/17 is one-fourth of what farmers harvested in the wet season the

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[4] After the rains refused to come for an average of 4 weeks.

previous year. Thus adaptive decisions involve using combine harvesters which is time efficient and reduces crop loss. For other farmers, the evidence of failed or a good year is predictable relational to activities preceding the activity of harvesting. Thus, a manual harvesting method could be used to save financial resources.

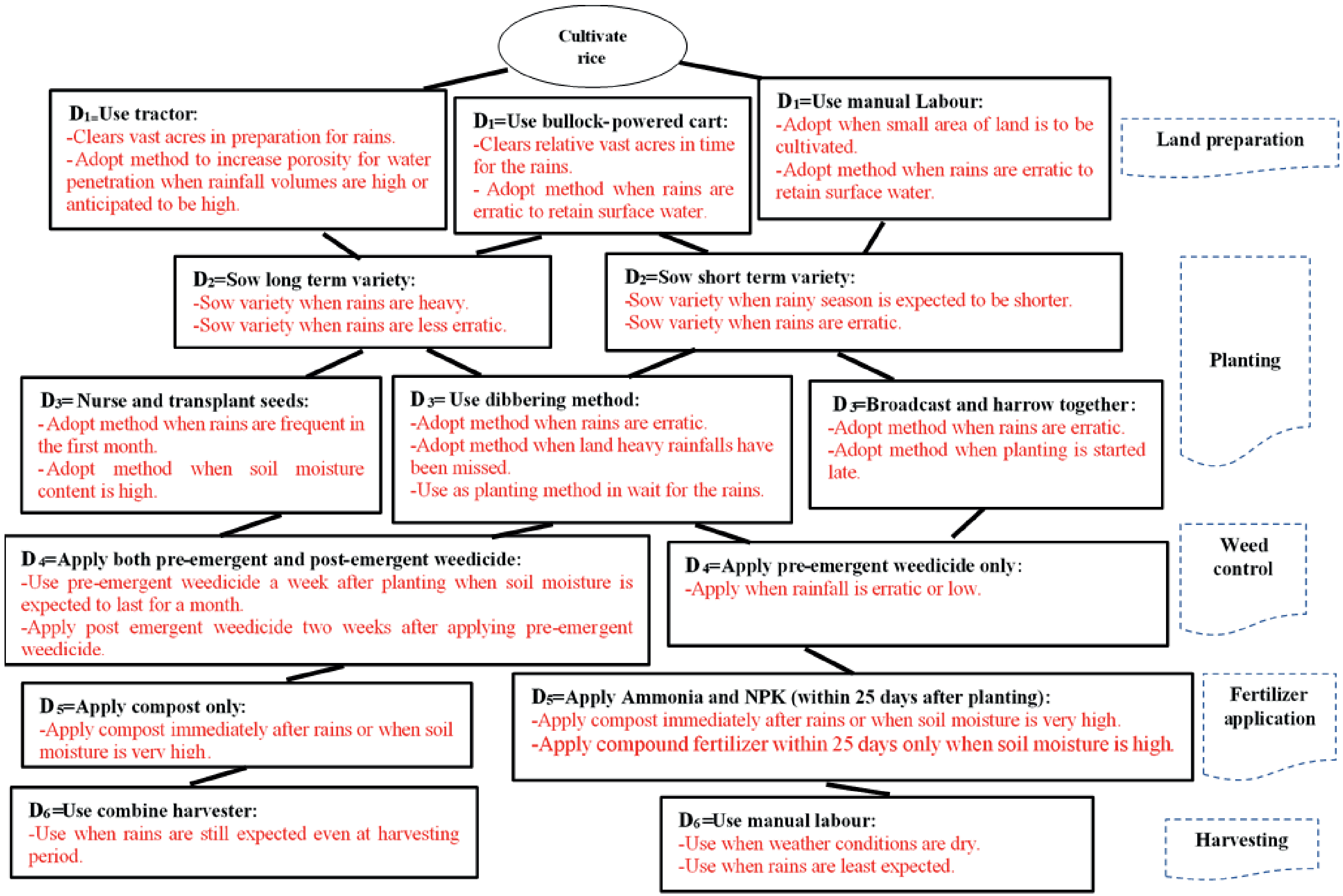


Figure 3.3: Adaptive decision-making in rice farming systems

3.4.4 What governance arrangements exist in rice farming systems?

Two types of governance arrangements can be identified in rice farming systems. Within the irrigated rice farming system, formal governance arrangements with legal orientations can be seen to shape activities and interactions. Traditional governance arrangements although pre-dominant in rain-fed rice farming systems had an impact on activities in irrigated rice farming.

3.4.1.1 Rain-fed farming systems

Under rain-fed systems, decision-making is less coordinated and centres on household and community members. At the onset of the season, farmers mostly consult members of their households in taking decisions. Other farmers within the community are also consulted when planning for the season. Farmer decisions are shaped by the rules and norms largely defined by communities. Communal decision-making is led by traditional authorities, religious leaders and locally elected leaders such as the Assembly member. Conflicts amongst farmers are also resolved at chief palaces under the leadership of chiefs and elders. Chiefs as custodians of communal owned resources such as land and water resources ensure all inhabitants are able to meet water needs. For rice farmers, meeting household water needs is equally a priority as water for irrigation purposes. The chief's palace is thus a safe haven to manage conflicts on water use.

Men wield a lot of authority at the household level as heads of households. Traditionally, land is willed to male members of the household as women are expected to eventually change names after marriage. Household names are thus traced through male descendants. This automatically limits the ability of female farmers to access land or expand area under cultivation. Women involved in rice farming mostly work with their spouse. Culturally, women are perceived as 'helpers' and hence are required to support their spouses on the farm rather than cultivate vast acres of land. Hence, the potential of women is limited to their engagement by their husbands. The high sense of communalism serves as a useful resource in meeting labour costs on farms. Here, rice farmers receive labour support from other community members for reciprocation on their farmlands. This is typically the case in smaller communities such as Kpegu-Biegu, Voggu and Kpegu-Bagurugu.

3.4.4.2 Irrigated rice farming

Operations within the scheme are guided by formal governance arrangements at the national, regional and local levels. At the national level, the Ghana Irrigation Development Authority (GIDA) gives mandate to operations within the scheme. The Environmental Protection Agency (EPA) and the Water Resources Commissions (WRC) grant user rights on water use for irrigation purposes. Operations at the scheme level are led by the Manager. The scheme manager periodically consults the Ghana Meteorological Agency (GMA) for weather information which guides decisions on water use. The Savannah Research Institute (SARI) also provides scientific information to inform agronomic practices.

The scheme manager leads decision-making at the scheme level. Technical decisions on management of the dam and ancillary facilities within the scheme are matters of interest. Farmer associations exist with leadership responsible for liaising between farmers and management. Farmlands are put in blocks with leaders responsible for managing laterals and monitoring water distribution for irrigation purposes. A schedule is drafted at the beginning of the year on how and when water will be discharged to laterals. Block leaders work closely with leaders of their respective farmer associations for farm level decision-making. Sub-committees set up (as part of L.I 350 of the Irrigations Development Authority) to augment efforts of the manager include the Maintenance, Finance, Marketing and Welfare committees. Traditional authorities whose lands fall within the catchment area of the dam and own farmlands are also primary stakeholders in the context of decision-making on water use. Traditional authorities are also consulted by the scheme manager in managing conflicts on water use.

3.4.5 How do governance arrangements enable or constrain adaptive decision-making?

Considerably, governance arrangements impact adaptive decisions made under both farming systems. These arrangements in some context propelled and improved adaptive decisions whereas other arrangements appeared as limiting factors.

3.4.5.1 Rain-fed rice farming

Governance and decision-making are not mutually exclusive under the rain-fed system. Farmers who cultivate rice under this system operate within the cultural and social settings shaping norms, rules and beliefs in their communities. For example, although farmers take decisions at the household level, they are expected to adhere to directives from chiefs, unit committee members, the assembly member, other leaders even if unfavourable but in the interest of the community. With the existence of multi users of the Bontansi River, rice farmers are required to consider the interests of other users such as other crop farmers, livestock keepers and households. From section 4.1.1 rain-fed rice farmers mostly rely on the weather in meeting water needs for activities such as planting. Farmers equally explore alternatives such as the use of small water pumps to discharge water from tributaries of the Bontansi River unto their farmlands. The scuffle for water by various users sometimes results in pollution of the water making it unwholesome for their use. This poses a challenge to farmers in meeting water needs and adaptive decision-making. Cultural practices within communities for example prohibit women from leading the decision-making process especially in male headed households. This has impact on their input on key decisions. Thus adaptive decision-making is male centred limiting the possibility of reducing risks and social learning. As seen in section 4.1.1, land is also mostly owned by men thereby limiting the ability of women to contribute directly to increasing production under uncertain water sensitive conditions.

Nevertheless, the spirit of communalism is an enabler of adaptive decision-making in some circumstances. For example, the fact that rice farmers live within the same community as some owners of bullock-powered ploughs enable access to their services on credit when they have to prepare their lands for planting as presented in 4.1.1. Labour needs during planting are also met as a result of 'labour-for-labour' governance arrangements. Here, farmers take turns to support each other during planting, fertilizer application and harvesting. This enhances the capacity of farmers to adaptively decide their actions. Strong community cohesion patterned by traditional rules of engagement also allow for collective decision-making in managing challenges of water availability. From section 4.1.1 it is evident that farmers spend time interacting and sharing knowledge in open spaces at random or agreed times at all stages of their decision-making. In Sakuuba for example, community meetings organised by chiefs afford them the opportunity to discuss water conflicts and how best to manage them. Through adaptive decisions, water users within the community are able to improve water management practices which equally translate to better conditions of water availability for rice farming.

3.4.5.2 Irrigated rice farming

The regulatory framework (L.I 1350- Ghana Irrigation Development authority Act, 1987) defining operations within the irrigation scheme explains authority and power relations. Here, the Scheme manager is seen as the final authority at the scheme level and hence controls water user rights. Under the leadership of the scheme manager, periodic meetings are held for broad decisions which affect all actors within the irrigation scheme. This usually comprises of the scheme manager, water bailiffs, block leaders, lateral managers and farmers. Thus, key decisions as outlined under section 4.1.2 begin with discussions which have water management at the core. Thus strategic water dependent adaptive decision-making begins at the managerial level with most tactical decisions taken by farmers at the farm level. For example, from section 4.2.2, water bailiffs guided by agreed schedules discharge water to irrigate farmlands. Farmers however take the tactical adaptive decisions of water sufficiency on their farms. Farmers monitor their farms and are able to control inflow to avoid flooding. The presence of scheduled timelines for irrigation highly influences farmer decisions on when to plant, apply weedicides and also fertilizer on their farmlands.

Contrastingly, farmers can also not decide to discharge water to irrigate their farms at their own timing but rather follow agreed schedules even during emergencies. During dry seasons, water discharge comes with power play with some chiefs continuously receiving water on their farmlands at the expense of other farmers. Also, laterals 1 to 7 conveniently access water even during the dry season as opposed to laterals 8 to 14. The exhibition of powers thus creates a situation where Chiefs, leadership of farmer groups and farmers favoured by them are mostly able to secure lands within laterals 1 to 7. Thus for farmers with less influence, their decisions must consider such risks and how these could be constraints towards adaptive decision-making. In essence, water dependent adaptive decision-making is not mutually exclusive of rules and processes already defined as part of water management strategies and agreements.

The institutional space within which stakeholders relate significantly impacts decision making processes and outcomes. These include formally entrenched frameworks such as constitutions, ad-hoc rules of engagement and organograms defining hierarchy and power in public and private spheres. Similarly, undocumented laws, rules and norms which are usually embedded in the cultural fabric of communities explicitly or implicitly construct the process of decision-making, framing the boundaries for who, what and when decisions could be made. Adapting in a highly volatile environment such as the one in which rice farmers operate requires a continuous process of cognitive revision through experimentation, learning and re-adjustment in adaptive decision-making.

The existence of a regulatory framework within the scheme also means that farmers operate in line with communication and power symmetries. From section 4.2.2, the lateral manager (one voluntary farmer plays this role at a particular time) is the first point of contact for farmers should they have challenges with water flow on their farmlands. He is then expected to forward concerns to the water bailiff in the absence of an immediate solution. With the scheme manager at the end of the bureaucratic complaint chain the timing of farmer decision and implementation of adaptive actions in relation to water management on their farms is affected. From 4.2.2, farmers, as a rule, are required to desilt canals that convey water unto their farms. Thus, for a farmer downstream, the efficient and timely undertaking of this activity by another farmer upstream is critical. For example, soil moisture at the point of fertilizer application must be high or sufficient. In the case of non-adherence by some farmers to desilt canals, those downstream potentially are faced with stunted growth of their rice due to low moisture conditions. The weak implementation of punitive measures also means that farmers who refuse to clear their laterals could only be cautioned by block leaders and/or lateral managers. The existence of informal relationships and the culture of respect for 'senior citizens' within communities limit the ability of lateral managers to enforce rules to the core. Leaders of farmer associations equally enjoy some priority when farmers are to benefit from interventions such as trainings, seminars and out-of-farm collaborative arrangements with private institutions. The absence of a system for knowledge transfer also means that leaders who benefit from such capacity building are not obliged to transfer knowledge acquired. Hence, some farmers are at risk of losing relevant information which could improve their adaptive decision-making.

3.5 Discussion

In this section, we discuss the implications of our results and the relationship between key concepts as studied in both rice farming systems. We further attempt a so-called ex ante reflection spelling the potential of hydro-climatic information to inform adaptive decision-making. We further estimate how governance arrangements could enable or inhibit information access for adaptive decision-making. In essence, our conclusions and propositions related to the potential of hydro-climatic information and EVOs in adaptive decision-making is based on reflections.

3.5.1 Reflection on key concepts: adaptive governance and adaptive decision-making

In our attempt to contribute to theoretical dispositions on adaptive governance of food systems, the study focused on governance arrangements and adaptive decision-making in rice farming systems. It emerged that governance arrangements evolved with learning and experimenting in adaptive decisions-making. An inverse relationship could also be identified with adaptive decisions being streamlined in response to adaptive governance arrangements (Feola, Lerner, Jain, Montefrio, & Nicholas, 2015). Both conditions are due to the consistent shift in ecological variables such as river discharge, temperature and rainfall rendering supposed solutions expressed in adaptive decision-making becoming part of the problem or rather ineffective thereby requiring newer strategies and actions. Also, formal and traditional governance arrangements were found to be interwoven given the involvement of farmers in both systems. In establishing further the place of both governance arrangements in adaptive decision-making, the study concludes that formal governance arrangements must have traditional governance arrangements as sub-structures in their design or a complement of both.

We conclude that studies on adaptive governance of food systems must empirically explore the relationship between governance arrangements and adaptive decision-making (especially in water governance) (see also Rouillard, Heal, Ball, & Reeves, 2013; Dewulf, Mancero, Cárdenas, & Sucozhanay, 2011). We equally admit that although the study stepped out to study adaptive governance, it focused on only two key components of the theory; governance arrangements and adaptive decision-making. Thus, our conclusion will better reflect the theory only in the context within which it has been applied.

3.5.2 Governance arrangements and the potential of hydro-climatic information

3.7.2.1 Under rain-fed systems

Traditional governance arrangements put Chiefs and other community leaders at the forefront of decision-making within communities. Inhabitants of communities willingly submit to calls from the aforementioned for collective action and decision-making on matters of importance. The platform created by traditional leaders serves as a medium for information dissemination necessary for decision-making amongst rice farmers. Citizens as part of religious routines pray together at mosques and churches located within their communities. This creates avenues for channelling information. Also, farmers as a result of social networks defined by culture and lifestyle meet periodically to socialize and this creates an avenue for information sharing and exchange.

On the other hand, tradition also requires that community entry begins with consultation with Chiefs and community leaders. This arrangement means information service providers in trying to engage rice farmers must seek consent from Chiefs as they are the custodians of the land and rulers of the people. In the instant where permission is not granted, rice farmers will lose relevant information which goes a long way to improve their decisions. Also, citizens esteem knowledge handed over from older generations. In the instance where information from external providers contradict their traditional knowledge and processes, some farmers will reject new knowledge and continue with the old way of doing things. This can translate into low acceptance and use of new knowledge resulting in knowledge conflicts putting farmers at crossroads as to the way forward. Thirdly, weak interactions between the District Assembly and communities can limit the impact of programmes aimed at providing farmers with information through public sector programmes. The absence of rice farmer associations in communities could limit the dissemination of hydro-climatic information should they be made available. Although rice farmers meet periodically within communities, activities are less structured with no conclusive actions taken in pursuit of hydro-climatic information.

3.7.2.1 Within the irrigation scheme

Hydro-climatic information has can improve farmer decision on water use. Sam and Dzandu (2016) also attest to information relevance for food production in Ghana. This is however dependent on the extent to which governance arrangements make such possible. Arrangements within the scheme present a clear structure for information flow and decision-making. The scheme manager as part of overseeing general operations within the scheme channels relevant information either through leaders of farmer associations, members of ad-hoc committees or directly to farmers at meetings. Such organised arrangements create the opportunity for directly communicating hydro-climatic information received for use by farmers.

Currently, the partnership between GMA and GIDA has yielded positive outcomes such that GIDA is able to receive information on rainfall projections as estimated by GMA. Such information contributes to informed decisions on water use within the reservoir. However, the all year round availability of water in the dam for irrigation purposes within the scheme limits the urgency and need for hydro-climatic information. The variation in water level nevertheless makes it relevant to track hydro-climatic conditions via relevant information sources. Communication processes must adopt smart approaches such as the use of social platforms for quick dissemination of information where applicable.

3.5.3 Potential hydro-climatic information for adaptive decision-making

The availability of timely and reliable hydro-climatic information at each phase of decision-making can improve adaptation (see also Wood, Jina, Jain, Kristjanson, & DeFries, 2014) efforts in rice production systems. Farmers rely on traditional knowledge with some receiving information on daily weather forecasts. However, obtaining information on daily precipitation and temperature values which are area specific could improve adaptive decisions at different decision points (see also Aker, Ghosh, & Burrell, 2016). Hydro-climatic information received at the community level informs the planning of daily schedules for water discharge for irrigation within the scheme.

At the onset of the rainy season, the scheme manager together with farmers within the scheme design a daily schedule for water discharge from the dam unto farmlands. Here, information on rainfall and temperature values can contribute to a more precise strategy and outcome (see also Fosu-Mensah et al., 2012; Kemausuor, Dwamena, Bart-Plange, & Kyei-Baffour, 2011). For example, the water manager will be able to estimate likely water volumes within the dam. Plans on supplementary irrigation could be improved as information from GMA and private institutions show the periods where the area is likely to experience heavy rainfall. Information on temperature values for the area could also come in handy during the dry season when the rains have seized for effective planning on water use from the dam.

For farmers under rain-fed systems, information on daily and seasonal rainfall values could guide their decisions on whether or not to engage in rice farming as most rely on the rains directly to meet water needs on their rice farms. Chiefs, religious leaders, radio and local political representatives such as the Assembly member could serve as channels for information dissemination to farmers within communities (see also Aker & Fafchamps, 2015; Sam et al., 2017). During land preparation, information on rainfall is equally relevant for farmers under rain-fed systems. Here, farmers are able to plan the number of days they have to use in clearing their lands to avoid being caught up in heavy downpour which makes it difficult to use machinery such as tractors and tillers on the land. During planting farmers decide on whether to cultivate short term or long term varieties guided by experience and projections on rainfall for the season. Readily available information on daily precipitation comes in handy in making choices on variety to plant. The story at the point of fertilizer application is no different. Information on precipitation has the tendency of guiding decisions on what quantities of fertilizer to apply and when. This will curb the situation where fertilizer applied is washed away by the rains adding up to cost burdens and losses mostly borne by the farmer and his household.

3.5.4 EVOs and adaptive governance

Technology based platforms are today being developed to support natural resource governance through information management, improved stakeholder interaction and decision-making (see also Termeer & Bruinsma, 2016; Pimm et al., 2014; Buytaert et al., 2014). Decisions on irrigation and water use for example can be improved if farmers and water managers have access to timely information from relevant institutions. In adaptive decision-making discourse, information must not just be available but also timely and relevant for farmers and water managers.

Currently, two systems of governance exist in rice production systems in the Bontanga area with an enormous number of stakeholders involved. The situation has resulted in poor and unregulated interaction limiting the ability to deal with complex challenges faced by rice farmers. As it emerged, the Bontansi River is central to the activities of all rice farmers irrespective of which system they operated in. Hence creating the opportunity for stakeholder collaboration in water management could be beneficial. As argued by Termeer and Bruinsma (2016) however, there is the need to bridge physical, cognitive and social boundaries. EVOs thus present an opportunity for collaborative governance by providing the platform for interactive engagement, information sharing and the leap over social boundaries (Karpouzoglou et al., 2016a).

In the case of water management, an EVO that provides timely information and enables stakeholders to consolidate observed changes in weather conditions can essentially improve decisions on water use for irrigation. Here, the MSD, ISD, water managers and farmers can directly contribute to predicting weather indices irrespective of their location and rice production system being practiced. Local knowledge used by farmers in predicting the weather could be synthesised with scientific knowledge to improve predictability and make adaptation more locally relevant. Chiefs and leaders in communities studied could sensitize and stir interest of all stakeholders in communities to contribute to information gathering, discussions and creation of new knowledge for adaptive decision-making. Given that stakeholders under both systems admit to water dependent decision-making, a coordinated process which brings stakeholders together could be the beginning of realising the goal of an operational EVO for water management.

3.6 Conclusions

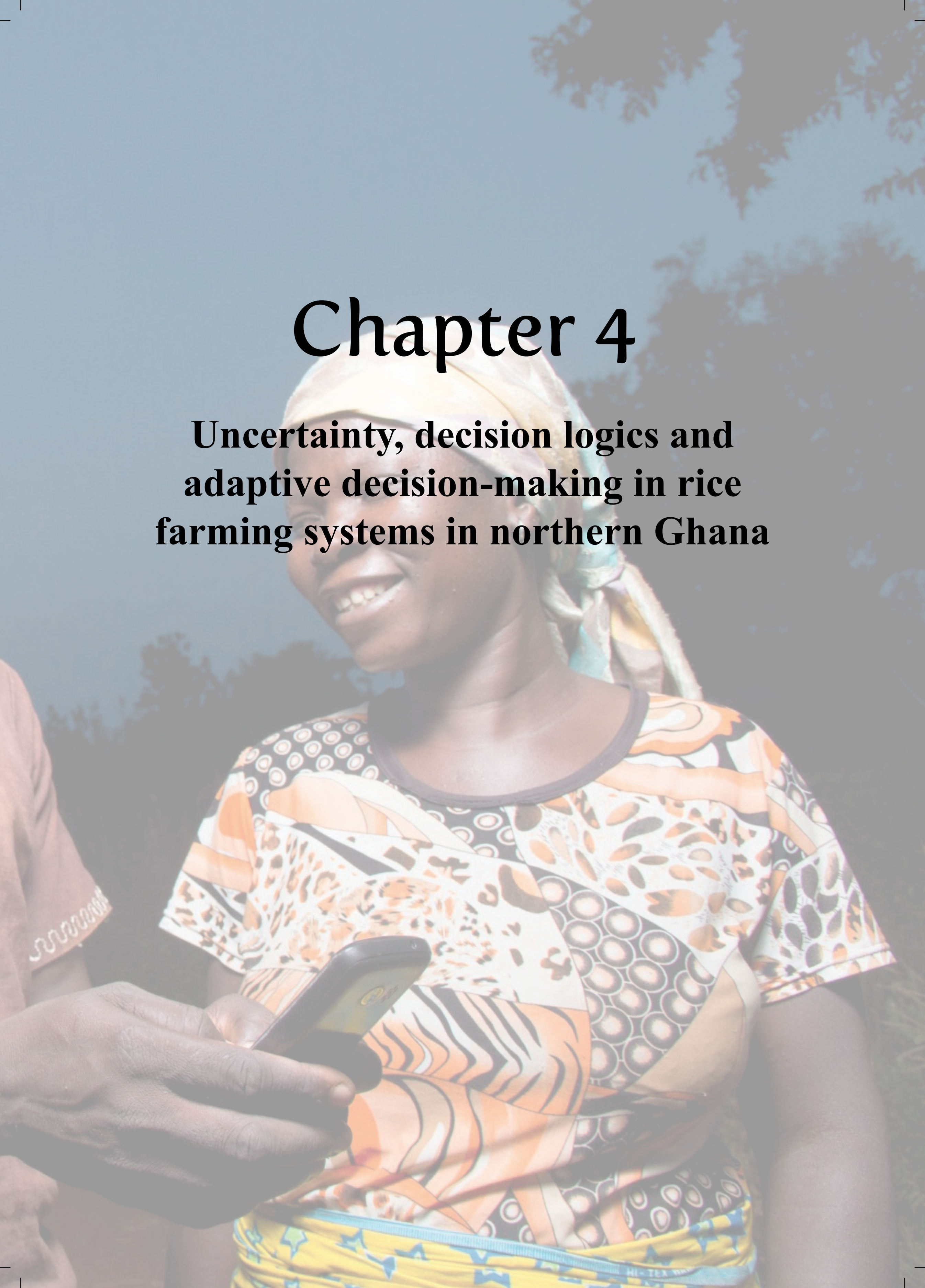
The study establishes a correlation between governance arrangements and adaptive decision-making in adaptive governance. Evidence from the field suggests that adaptive decision-making within irrigated and rain-fed rice production systems vary. Farmers under both systems operate within different governance arrangements which are both enablers and inhibitors given conditions. For adaptive governance of rice farming systems within the area, there must be a synergy of both formal and traditional governance arrangements as these are not mutually exclusive. Following our ex ante evaluation on the place of information in adaptive decision-making, we point to the need for further research on information access and use, power play, gender and information systems enabling information exchange and knowledge creation which essentially influence water dependent adaptive decision-making.

In Bontanga, bottlenecks to information exchange must be considered in the design of Environmental Virtual Observatories. Much appropriately, research on what information systems exist and how these are operationalised within current governance arrangements is critical. Water availability is central in both the design of governance arrangements and adaptive decision-making within the study area. This emphasises the significance of hydro-climatic information in the area hence the need to study what information exists, the knowledge they provide and the systems being deployed to disseminate them.

Acknowledgements
We acknowledge the numerous partners funding the EVOCA programme and research. We also thank the management of the Bontanga Irrigation Scheme and farmers who availed themselves to be part of the study and continuously support the EVO design process.

Chapter 4

Uncertainty, decision logics and adaptive decision-making in rice farming systems in northern Ghana



Abstract

Farmers in rice farming systems in Northern Ghana face uncertainties resulting from variation in climatic and social conditions and hence the need to adapt their decisions. The paper presents what substantive and institutional uncertainties farmers face and the underpinning logics evident in adaptive decision-making. The paper poses the overall question "What uncertainties and corresponding decision logics inform farmer adaptive decision-making?" Using an exploratory design, 135 rice farmers from 9 communities in the Kumbungu District were engaged through interviews and focus group discussions. The study showed that both the logic of consequentiality and the logic of appropriateness are underpinning factors in farmer adaptive decision-making. Some adaptive decisions underpinned by the logic of consequentiality include: multi-cropping; cultivating inside and outside the irrigation scheme and; vary planting date based on forecast. Adaptive decisions where the logic of appropriateness comes into play include: cultivating rice by convenience under defined land user rights and; adopting planting method used by other farmers. We conclude that hydro-meteorological forecast can help farmers manage substantive uncertainty by meeting information needs such as rainfall onset and distribution as well as hydrological information on dam water levels within the scheme. Also, forecast information provided without recognition of institutional uncertainty within farming systems could end up being ignored by some farmers.

Manuscript under review: Nyamekye, A. B., Dewulf, A., Van Slobbe, E., Termeer, K. Uncertainty, Decision Logics and Adaptive Decision-making in Rice Farming Systems in Northern Ghana. *Journal of Climate Services*.

4.1 Introduction

Climate variability in the form of change in rainfall patterns and temperature results in water scarcity, drought and flooding pose threats to agriculture and food production in sub-Saharan Africa. Most especially, smallholders suffer severely in meeting food and income needs from farming due to water scarcity, soil infertility and long periods of droughts (Cooper et al., 2008; Inder et al., 2017; Morton, 2007). In Ghana, climate variability threatens the activities of rural farmers in the Northern part of the country (Asare-Bediako et al., 2007; Donkoh & Awuni, 2011; Etwire, Al-Hassan, Kuwornu, & Osei-Owusu, 2013; Laube et al., 2012; Nyadzi et al., 2019; Nyamekye, Dewulf, Van Slobbe, Termeer, & Pinto, 2018). The region falls within the guinea savannah zone and experiences long periods of drought, high temperatures and erratic rainfall conditions, presenting farmers with numerous uncertainties in decision-making at the farm level (Antwi-Agyei, Fraser, Dougill, Stringer, & Simelton, 2012; Armah et al., 2011; Codjoe, 2007; Lançon & Benz, 2007). Recent studies (Mase & Prokopy, 2014; Roco, Engler, Bravo-Ureta, & Jara-Rojas, 2014) point to how the provision of hydro-meteorological information can minimize uncertainties and improve farmer adaptive decision-making. However, understanding what objects of uncertainty exist, and how these are reflected in farmer adaptive decision-making is crucial in determining farmer information needs.

In the Kumbungu district in the Northern region of Ghana, rice farmers cultivating rainfed or irrigated rice often need to adapt their decisions to meet water needs when relying on rainfall or supplementary irrigation. Adapting their decisions means that farmers must observe and attempt to manage uncertainties about future events especially regarding the availability of water. Here, the pursuit of information on weather and seasonal forecasts from both scientific and indigenous sources is of priority to farmers (Balehegn, Balehey, Fu, & Liang, 2019; Kanno et al., 2013; Nyadzi et al., 2019).

Increasingly, research on uncertainty and adaptive decision-making in farming is on the ascendancy (Beckford, 2002; Dittrich, Wreford, Topp, Eory, & Moran, 2017; Li, Guo, Bijman, & Heerink, 2018). This is attributable to the high sensitivity of farming activities to volatile conditions such as climate change, environmental degradation, resource conflict, urbanisation and institutional change (Crush & Battersby, 2016; Daher & Mohtar, 2015; Eakin, 2005; Nyadzi et al., 2018). Similarly, numerous studies have pointed to the need for reliable and timely provision of relevant seasonal and weather forecast in managing uncertainties in farming systems (Ali & Kumar, 2011; Jones, 1993; Kabir, Cramb, Alauddin, & Gaydon, 2019; Mase & Prokopy, 2014; Pannell, 2003; Zheng et al., 2011) to improve farmer decision-making. However, defining seasonal and weather forecast also requires accounting for the interaction between uncertainties, information needs and farm level adaptive decision-making. Firstly, the forms or objects of uncertainty that farmers are faced with in adaptive decision-making is under-researched. Recent studies have focused on biophysical aspects of climate uncertainty through improved modelling (Berliner, 2003; Burnham, Ma, Endter-Wada, & Bardsley, 2016; Kundzewicz et al., 2018; Xia et al., 2017). The works of Heal and Millner (2013) and Drouet and Emmerling (2016) are a few that point to broad socio-economic uncertainties relating to climate change. Secondly, although research on adaptive decision-making has gained traction, much emphasis is placed on decision options and not the logics underlying farmer adaptive decision-making (Gebrehiwot & van der Veen, 2013; Moller, Drews, & Larsen, 2017).

The paper aims to contribute to literature on how uncertainty impacts adaptive decision-making and how the provision of relevant hydro-meteorological information can improve farmers' adaptive decision-making in rice farming systems. The paper also explores the logics of decision-making underneath adaptive decision-making at the farm level in better interpreting decisions. The paper makes reference to two decision logics: the logic of consequentiality and the logic of appropriateness anchored on the work of March, (1991). Both logics provide a pathway to understanding adaptive decision-making given uncertainty and information. Most studies have used economic models (Güth, 2004; Pascucci et al., 2015; Risbey et al., 1999) which rather make it difficult to measure the complexity of human behaviour (Ascough, Maier, Ravalico, & Strudley, 2008; Karali, Rounsevell, & Doherty, 2011). Other studies also opine that decision-making is not always profit oriented but follows multiple pathways induced by economic, social, psychological, biophysical and ecological issues (Robert et al., 2017; Moller et al., 2017). However, there is the need for a framework 'that enables the uncertainties associated with human inputs to be accounted for explicitly' (Ascough et al., 2008) in adaptive decision-making.

A key question is do farmers in their response to abnormal or unexpected conditions consider the outcome of their choices (logic of consequentiality) or rather the practice driven by changing rules (logic of appropriateness) in adaptive decision-making? In addressing this scientific gap the paper poses the overall question "What uncertainties and corresponding decision logics inform farmer adaptive decision-making?". In line with this the study poses four (4) specific questions:

i. which decision logics guide farmers' decisions?
ii. what uncertainties do farmers face when taking those decisions?
iii. which decision options are more adaptive?
iv. what information can inform these decisions?

4.2 Theoretical framework

Uncertainty within social and ecological systems is the reason why decision makers have to adapt their choices and actions in order to optimize utilities. Focusing on decision-making, Brugnach et al. (2008) conceptualised uncertainty as 'a knowledge relationship between a decision maker and the socio-techno-environmental system at hand' due to unpredictability, incomplete knowledge and multiple knowledge frames. Dewulf and Biesbroek (2018) in conceptualizing uncertainty posit 9 types of uncertainties with reference to the works of Kwakkel et al. (2010), and Koppenjan and Klijn (2004). Dewulf and Biesbroek (2018) discuss the nature of uncertainty by including ambiguity to those already discussed (epistemic and ontological uncertainty) in literature, and discuss institutional and strategic uncertainty as objects of uncertainty in addition to substantive uncertainty evident in other studies (Brugnach, Dewulf, Pahl-Wostl, & Taillieu, 2008; Kwakkel, Walker, & Marchau, 2010).

This paper focuses on two of the objects of uncertainty: substantive uncertainty and institutional uncertainty. Koppenjan and Klijn (2004) define substantive uncertainty as uncertainty regarding the content of decisions due to either the lack of information or diverging frames about the information. Dosi and Egidi (2000) attribute substantive uncertainty to the lack of information about environmental events. Substantive uncertainty is also associated with gaps and conflicting understanding in knowledge with the consequence that there is limited understanding of the nature of a problem (Head, 2014). Institutional uncertainty refers to ‘uncertainty about the rules of the game in decision-making’ (Koppenjan & Klijn, 2004) and how they transform. Institutional uncertainty is a result of expected change in institutional arrangements.

We also draw from decision-making literature anchored on the seminal works of March and Olsen on neo-institutionalism (March, 2011; March & Olsen, 2004; Olsen, 2007). The authors introduce two logics characterising decision-making: Logic of Consequentiality (LoC) and the Logic of Appropriateness (LoA). They relate the LoC to standard theories of choice which perceive decision-making as intentional in the presence of knowledge of alternatives, a knowledge of consequences, a consistent preference ordering and decision rules. It is the logic of calculation and ‘rational choice’ among alternatives (Rommetvedt, 2006). Decision-making is ‘consequential-and within the limits imposed by information constraints and conflict-intendedly rational’ (March, 1991). On the other hand, LoA perceives human action to be driven by rules of exemplary behaviour, organised into institutions (March & Olsen, 2004). March and Olsen earlier somewhat prioritized the logic of appropriateness over the logic of consequentiality until recently (Rommetvedt, 2006). LoA contends that decisions are shaped by situational contexts, one’s identity and the application of rules (Weber & Johnson, 2009).

We assume a relationship between uncertainties and logics of decision-making in adapting to changing conditions in rice farming systems. Cleary, LoC assumes that decision makers consider what alternatives they have and their possible outcomes considering information available. Koppenjan and Klijn (2004) point to substantive uncertainty as the lack of information or divergent frames of information. Such substantive uncertainty is of importance to decision-making aligning with the logic of consequentiality. The reference to institutional uncertainty points to uncertainty about rules and how they serve as underpinnings of decision-making in line with the logic of appropriateness (Dewulf, Klenk, Wyborn, & Lemos, 2020). Thus, decision-making in rice farming systems can be adaptive in response to substantive uncertainties surrounding decision choices based on the logic of consequentiality or in response to institutional uncertainties pertaining to decision rules based on the logic of appropriateness.

Predominantly, studies aimed at understanding decision-making emphasise the rationalist logic of consequentialism rather than institutionalist logic of appropriateness (Beckford, 2002; Börzel & Risse, 2003; Best, 2009; Michelsen, 2009). However, farmer behaviour is also “entangled in on-going processes of social-ecological change and their associated politics” (Manuel-Navarrete & Pelling, 2015, p. 559) suggesting that decisions could also be aligned with rules of behaviour influenced by the social context. Farmers make tactical decisions based on the socio-political and cultural setting of their region. Establishing whether farmers are adaptive also requires introducing into the debate how other logics rather than the consideration of consequences brings them closer to being adaptive and what this necessitates in terms of information needs.

We draw on the work of Nyamekye et al. (2018) who differentiate between regular decision-making and adaptive decision-making. They define regular decision making as “the process of choosing standard decision options, based on generalized expectations of what to do under normal circumstances, but independent of the observed or anticipated environmental conditions that present themselves”. They contrast adaptive decision-making to mean the “process of choosing non-standard decision options, in response to circumstances that are considered abnormal or unexpected”. Given the context of this study, we define adaptive decision-making as “ taking into account substantive uncertainty when assessing consequences or taking account into institutional uncertainty when assessing appropriateness”. Given that some decisions could be non-adaptive, we also conceptualise non-adaptive decision-making. The conceptual framework is summarised in Table 4.1.

Table 4.1: Understanding adaptive decision-making

Logic	Decision-making	
	Adaptive	**Non-adaptive**
Consequentiality	Takes into account substantive uncertainty when assessing consequences	Does not take into account substantive uncertainty when accessing consequences
Appropriateness	Takes into account institutional uncertainty when assessing appropriateness	Does not take into account institutional uncertainty when assessing appropriateness

4.3 Research methodology

4.3.1 Research design

The study adopts an exploratory approach (Jebb, Parrigon, & Woo, 2017; Nuzzo, 2014; Patton, 2005; Patton, 1990) to ascertain hydro-meteorological information needs and decision-making contexts in rice farming systems. The approach sought to inquire as to how these key variables are interconnected in rice farming systems. The longitudinal study involved direct participation and engagement with farmers over a period of 6 months of the cropping season.

4.3.1.1 Case study

The Kumbungu district, located within the Northern region of Ghana was selected for the study. The region falls within the Guinea Savannah agro-ecological zone and experiences a mono-modal rainy season between May and October (Quaye, Adofo, Madode, & Abizari, 2009). The district is located in the Northern flank of the region with a land mass of approximately 1,599km sq. The period of July to September is the peak period of rainfall (average rainfall of 1000mm) with the district experiencing flooding in some communities (NDPC, 2019) whereas the rest of the year is dry. The district comprises 115 communities with Kumbungu as capital. The District shares boundaries to the north with Mamprugu/Moagduri district, Tolon and North

Gonja districts to the west, Sagnerigu Municipal to the south and Savelugu Municipal to the east (Abdul-Malik & Mohammed, 2012). Soils in the area are sandy loamy with alluvial deposits in low lands. Periodic burning of vegetation has exposed the soil to erosion and impacted soil fertility. The district is home to the Bontanga irrigation scheme with 13 communities within the catchment area of the Bontanga Dam (Zakaria et al., 2013). Agricultural activities dominate livelihoods in the district and is practiced mainly on seasonal and subsistence levels. Crops and vegetables cultivated include rice, sorghum, maize, millet, cowpea, groundnut, tomatoes and pepper (Quaye et al., 2009). We present a map of the district in Figure 1.

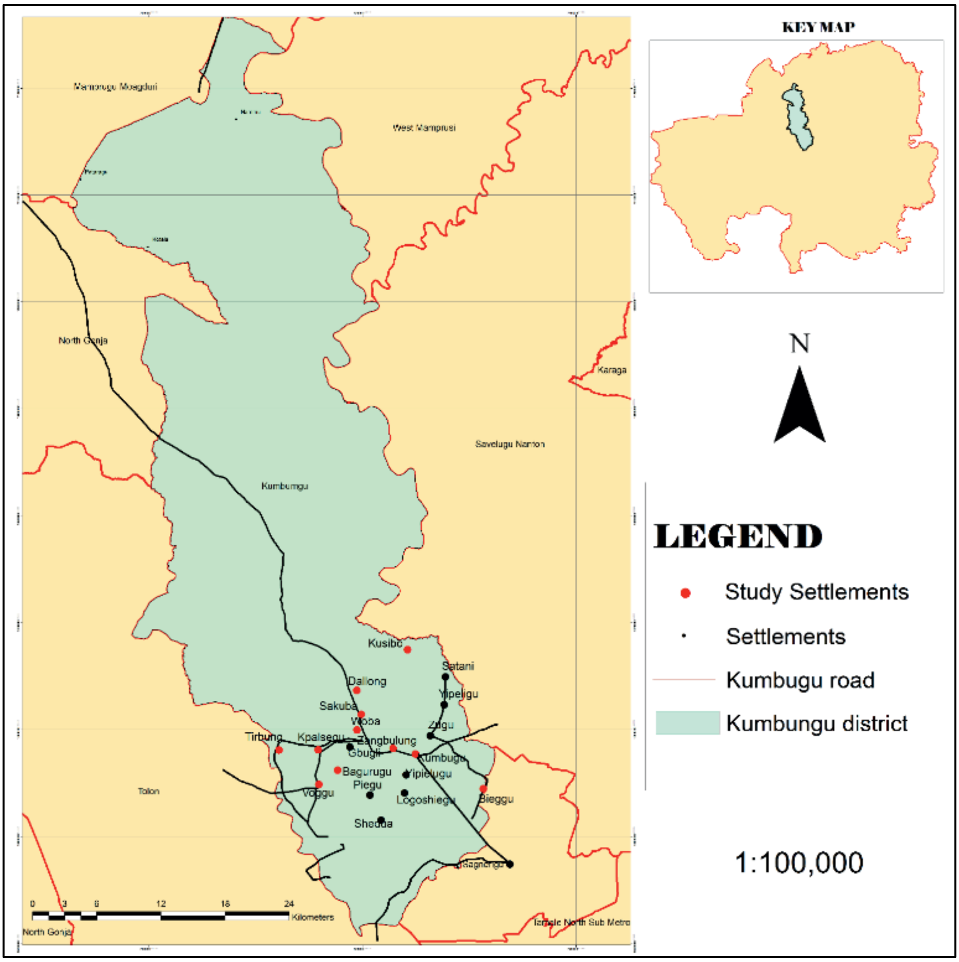


Figure 4.1: Map showing sampled communities in the Kumbungu district

4.3.1.2 Data collection

Data was gathered between the months of May and September, 2018 during the main cropping season. A total of 9 communities within the district were purposively selected given the presence of rice farmers involved in either irrigated or rainfed rice farming or both. Communities selected include Bontanga, Wuba, Yiepelgu, Dalung, Voggu, Tibung, Zangbalun, Kpegu-Biegu and Kpegu-Bagurugu. A total of 135 farmers were engaged through direct interviews and Focus Group Discussions (FGDs). Frey (2018) defined a focus group as 'a type of group discussion about a topic under the guidance of a trained group moderator'. In the context of interviews, a sample of 27 farmers (3 from each community) were directly engaged using interview guides with open-ended questions to obtain in-depth contexts of farmer adaptive decision-making (Magnusson & Marecek, 2015; George Mwangi & Bettencourt, 2017; Patton, 2005; Taylor et al., 2015). Furthermore, an average of 12 farmers were engaged in FGDs in each community for broader discussions and clarifications following individual interviews (Denzin & Lincoln, 2008; Kvale, 1996; Silverman, 2016). Three FGDs each were organised in all nine communities during the rainy season. FGDs were held in open spaces within communities and lasted an average of 45 minutes.

4.3.1.3 Data analysis

Data gathered was analysed using a deductive content analysis as described by Frey (2018). The method allows for confirming, expanding or refining existing understanding of a phenomenon. The process involved three stages: familiarization with data, initial coding and the generation of themes. To familiarize with the data, researchers reviewed responses from direct interviews and field notes taken during FGDs. The process allowed for the better framing of thoughts on how to approach the analysis. The second stage involved data coding through an iterative process. Here, key words and paragraphs in responses were grouped to condense data and obtain deeper meaning from the data (Krippendorff, 2018; Mayring, 2004; Neuendorf, 2016). A consistent unit of codes were generated for further analysis. Codes include for example, rules, choices, options, decisions, information needs, adaptive, non-adaptive, and uncertainty. The third stage entailed clustering of codes into themes such as appropriateness, consequentiality, adaptive decision-making, non-adaptive decision-making, substantive uncertainty and institutional uncertainty. Further narratives were put together explaining results.

4.4 Results

4.4.2 Logic of consequentiality and adaptive decision-making

In this sub-section, farmer adaptive decisions underpinned by the logic of consequentiality are highlighted. Reference is also made to what substantive uncertainty farmers faced and choices available to them to manage them.

D_1: What crop to cultivate

Pre-season preparations also involves decision-making on what to grow. Farmers with reference to seasonal forecast received take a decision on whether to grow rice as well as other crops such as maize, millet, cowpea, tomatoes and pepper. Based on consequential considerations farmers choose either to cultivate rice only, or rather other crops or both. Guided by the consequentiality logic, farmers make an adaptive decision to cultivate multiple crops as a hedge against crop failure under bad seasonal and weather conditions. Here, farmers can harvest other crops should rice fail due to bad seasonal and weather conditions. The non-adaptive choice is to cultivate rice only irrespective of expected changes in seasonal conditions. Thus, under wet, dry or normal conditions, such farmers continuously cultivate rice.

D_2: Cultivate rice both within and outside the irrigation scheme

Rice farmers who owned or had access to land both within and outside the irrigation scheme have to take a critical decision on cultivating rice both within and outside the scheme. For those who practice rainfed rice farming but decide to plant under irrigation as well, the pursuit for land access within the irrigation scheme also becomes a priority. Such decision is underpinned by the logic of consequentiality as farmers consider information available and consequences of the choice they make. Choices include cultivating rice under irrigation only or rainfed only or both. Given substantive uncertainty associated with seasonal forecast (wet, dry or normal), the adaptive choice made by farmers is to cultivate under irrigation within the scheme in addition to cultivating rice under rainfed. The availability of water for supplementary irrigation from the dam within the scheme minimizes the risk of crop failure under unfavourable seasonal and weather conditions. Non-adaptive choices on the other hand include sticking to a constant practice of rice farming under rainfed only or irrigation only irrespective of substantive uncertainty in forecast.

D_3: How to prepare land for cultivation

As earlier indicated, farmers take initiatives to prepare their lands for cultivation when the season begins. Weather forecast received at this point is crucial as farmers need very conducive conditions in terms of soil moisture content to prepare their lands. Here, farmer decision in terms of what method to use is anchored on consequences of the choice in terms of it enabling the farmer to prepare the land in time towards planting. Choices available to farmers include the use of tractor, bullock powered cart or manual labour in preparing the land. Here, an adaptive choice is to vary the clearance method considering observed and anticipated weather conditions. Thus, farmers opt for a tractor to plough the land when large acres of land is to be cleared under limited time before heavy rains. The choice to use bullock powered cart is applied when smaller acres of land has to be cleared also under less wet conditions. On the other hand, manual labour is used when farmers begin land preparation early and have ample time to prepare their lands before the rains finally set in fully. Varying the method for land preparation in view of forecast information puts farmers in a better position to manage substantive uncertainty regarding suitable soil moisture conditions. Contrastingly, using manual labour irrespective of seasonal conditions as indicated by some farmers is a non-adaptive choice with implications on productivity. For instance in the context of high soil moisture and wet conditions, the use of manual labour is less effective as compared to a tractor resulting in prolonged delay in completing land clearance.

D_4: When to plant rice

Although the rainy season begins in the month of May, the decision on when to plant could be varied depending on seasonal and weather forecast information on rainfall and temperature as estimated through indigenous observations or what is received via information systems. Planting is mostly done between the last week of May and late June. Farmers make a choice between sticking to their regular planting times as done in previous years or rather vary planting dates (either earlier or later) based on their knowledge of events and consequences of each choice. Substantive uncertainty exists here as to whether enough rains will be experienced between May and June and if so its distribution. The varying of planting date is perceived as a more adaptive choice than sticking to a particular time in spite of anticipated or observed conditions. Under rainfed rice farming systems especially, obtaining relevant information at this point is essential to making an adaptive choice. Within irrigated rice farming systems however, supplementary irrigation makes it less sensitive of a decision on when to plant as farmers are mostly able to meet soil moisture needs and water for irrigation.

D_5: How to and what rice variety to plant

Farmers mostly plant rice in the last week of May through till the end of June. Here, decision on the method for planting and variety of rice to plant of planting is sometimes defined by substantive uncertainty considering weather and seasonal forecast. Farmers choose between broadcasting seeds; using the dibbling method or nursing and transplanting later. The adaptive choice is to vary the planting method depending on estimated water availability conditions based on observed and forecast and soil moisture content. The choice of nursing and transplanting is pursued when normal or dry conditions are expected and hence nursing and transplanting later improves the resilience of crops to harsh or dry conditions. Farmers also nurse and transplant when late onset of rains are expected. In the case where rains set in early and farmers have limited time for planting, they opt to broadcast seeds to avoid missing the period of heavy rains and wet conditions necessary for rice to sprout. Farmers opt for dibbling when soil moisture is high and not much luxury is available in terms of time. A few farmers used the same method of planting irrespective of how this affects their productivity and ability to adapt to future weather variation. A non-adaptive choice is to stick to broadcasting irrespective of conditions. Such farmers are at higher risk of seeds being washed away especially under wet conditions. Although this probably works under normal conditions, the practice is mostly ineffective under extremely wet conditions. The stage also involves choice making on variety of rice to cultivate. Tying the decision on what variety to cultivate to conditions at each point in time is an adaptive choice to make. Hence given the factor of substantive uncertainty associated with seasonal forecast information, choices here include sowing drought resistant varieties when the season is expected to be dry, and a flood resistant variety when it is expected to be wet. This enhances probabilities of good harvest and returns on investment.

D_6: How to control weed

Weed control also requires farmer sensitivity to substantive uncertainty about rainfall conditions. Under conditions of uncertainty, farmers can choose between applying only pre-emergent weedicides or both pre-emergent and post-emergent weedicides. In the context of a wet season and normal conditions, farmers applied both pre-emergent and post-emergent weedicides. A non-adaptive choice made by farmers irrespective of consequences is to only apply pre-emergent weedicides with less recourse to meteorological forecast.

D_7: How to fertilize soil

The point of fertilizer application is one of the sensitive and crucial stages of the cropping cycle. Farmers have to ensure there is enough soil moisture for fertilizer absorption by crops but at the same time require some level of certainty on the timing of the rain to avoid the fertilizer being washed away. Farmers make a choice of either applying compost only, compound fertilizer only or both. According to the farmers, the adaptive choice is to apply both fertilizers. Here, farmers apply compost fertilizer 2 weeks after planting and NPK (nitrogen, phosphorous and potassium) within 25 days after planting. Farmers manage substantive uncertainty evident with weather conditions and change especially on rainfall amount and distribution when they make this choice. Thus, farmers in dealing with such uncertainty plan for a double phased fertilizer application much more also when seasonal forecasts point to normal or dry conditions during the main cropping season. However, a few farmers make a non-adaptive choice of applying only compost within the first 25 days of planting rice.

D8: How to harvest rice

The season ends with the harvesting of farm produce. The pursuit of meteorological information is for insight into the cessation of rainfall which is relevant in deciding on how to harvest. Farmers make a choice between using manual labour or engaging the services of a combine harvester. Harvesting using manual labour requires more labour days hence mostly opted for when there is enough time after cessation of rains. A combine harvester is a better choice when cessation delays and farmers have limited time for season closure. Adaptive decision-making involves choosing a method based on cessation as presented in a forecast. A non-adaptive choice is where farmers stuck to using manual labour always.

4.4.2 Logic of appropriateness and adaptive decision-making

Adaptive decision-making in some contexts also showed evidence of the logic of appropriateness at play by accounting for institutional uncertainty in decision-making. Adaptive decision-making in the logic of consequentiality accounting for institutional uncertainty due to change in rules over a period of time.

D9: Cultivate rice inside irrigation scheme with defined rules

Land ownership and tenure within the irrigation scheme is also a matter of concern especially amongst non-resident[5] rice farmers who patronize the irrigation scheme during the cropping season. Although resident farmers can lease lands, there is no clear formal arrangement or guideline on the process. For non-resident farmers such flexibility is shrouded in institutional uncertainty that they have to manage amidst the unavailability of information on any new arrangements as such occur at the farm level. Uncertainty about such rules means that non-resident rice farmers face the risk of not securing land within the scheme in a particular season unless they have full knowledge and can predict how these arrangements evolve. Thus rice farming for such farmers is highly tied to land access and user rights pushing them to adapt

[5] Farmers living outside the district who only come to farm within the irrigation scheme under agreed arrangements.

their decision to cultivate within the irrigation scheme along these conditions. Thus having clear arrangements with resident farmers in the rainy season on land tenure is seen as the ideal practice and the most appropriate thing to do. An adaptive choice is to cultivate only when land tenure and rental conditions are clearly defined. A second scenario occurs during the dry season where plots located within laterals 8 to 14 (upstream) within the irrigation scheme have limited supply of water when water levels in the dam reduce.

Thus farmers whose plots fall within laterals 8 to 14 or are non-resident resort to lobbying for land located within laterals 1 to 7 (downstream and mid-stream areas). The absence of clear rules about the process of allocation comes with uncertainty pertaining to access to land in the context of the aforementioned groups of farmers. Such institutional uncertainty impacts the decision-making process in line with the logic of appropriateness. Farmers whose lands are located within laterals 8 to 14 have to adapt by putting up rental arrangements to secure lands within laterals 1 to 7. Under the above scenarios, the non-adaptive choice is to cultivate rice within the scheme only when it is convenient to do so. Here, less attention is paid to how these rules are evolving but rather when the farmer determines is conveniently possible to farm.

D_{10}: Prepare land based on practices

Some farmers adapt by observing their neighbouring farmers. Such instances occur during land preparation where choice making is based on what is considered the appropriate choice. The choice to use manual labour or obtain a tractor is mostly collectively done as both options require greater numbers in making a case for such services. Farmers individual choices have a sense of reference to collective practices. Labour arrangements require wider consultation with other neighbouring farmers and households. Also, some farmers made a non-adaptive choice of using only manual labour due to the dominance of the practice amongst farmers and it being perceived as appropriate.

D_{11}: Plant seeds considering practices

Just like land preparation in some contexts, we see wider consultation with other farmers at the point of planting in decision-making on the method to adopt in planting or sticking to common practice as broadcasting which is known amongst farmers over the years. Common to farmers is the need to manage uncertainty about communal labour arrangements needed to support the activity of planting. As necessary, this requires a conscious pursuit defined by rules of engagement of the services of labour from their own communities.

D_{12}: Choose harvesting method informed by practice

Farmer decision on what method to use in harvesting is also based on perceived practices common to them at a point in time. Farmers pursuit of labour or combined harvester is based on collective practice. A non-adaptive practice however is the use of manual labour due to instituted labour arrangements with neighbours.

4.4.3 Information needs and managing uncertainties in adaptive decision-making

Given institutional and substantive uncertainty identified, our results also point to information needs relevant to improve farmer adaptive decision-making. Current meteorological information made available to farmers paid little attention to what different adaptive decisions farmers made, thereby limiting the degree to which information is interpreted as relevant and hence its subsequent use in decision-making. There is however the need for an elaborate outline of what specific forecast information farmers need and why their provision is eminent.

4.4.3.1 Information needs, substantive uncertainty and adaptive decision-making

Here, we infer what information is needed to reduce substantive uncertainty in current meteorological forecast made available to farmers over the farming period with reference to specific adaptive decisions identified.

a. What crop to cultivate

Although the decision to multi-crop is an adaptive-decision made by farmers, they indicated some information gaps exist which when provided could improve dealing with substantive uncertainty in adaptive decision-making. Farmers indicated the need for information on rainfall amount (wet, dry or normal) and distribution at the local scale. Given the high water requirement of rice and the low to average water requirement for other crops such as maize and sorghum, a sense of what rainfall amount to expect and its distribution informs the decision on what crops to cultivate to reduce risk of crop loss and capital cost. Information on rainfall onset and cessation at the local scale will also improve choice making on what crops to plant.

b. Cultivate rice both inside and outside the irrigation scheme

Farmers were also quick to indicate that cultivating rice both within and outside the scheme was risky due to unpredictability of rainfall and temperature conditions during both pre-season and in-season. Farmers indicated that forecast information must communicate rainfall onset and rainfall amount for the season (wet, dry or normal) at a local scale to improve adaptive decision-making. For farmers, this better informs their decision on the size area of land to cultivate especially under rainfed to reduce risk of crop loss.

c. How to prepare land for cultivation

Deciding on how prepare the land for rice cultivation is important. Key information required at this stage is onset, rainfall amount and distribution. A sense of the onset of the rains is deterministic for choice-making on what method to adopt in land clearance since for example clearing the land with manual labour is time consuming and hence not the best alternative when time is not a luxury with reference to rainfall onset. A sense of rainfall distribution is a good indicator of when land preparation should have been completed and preparations for planting started. Equally, information on rainfall amount in timing of the activity to avoid saturation and difficulty during land clearance.

d. How to and what rice variety to plant

As an adaptive decision, the choice to vary planting times is hinged on information on rainfall onset. With such information farmers consider which times will be most favourable to plant with an expectation of enough rainfall to minimize crop failure. Although current meteorological information communicated comes with information on probabilities, farmers indicated that rainfall amount is highly relevant in choice-making on what variety of crop to cultivate. Knowing if the season will be wet or dry is a good pointer in deciding whether to cultivate a flood tolerant variety which is long term or drought resistant variety which is short term. Probabilities communicated at the local scale will also inform the decision of cultivating either a drought resistant or flood tolerant variety.

e. How to fertilize soil

The point of fertilizer application comes is one of the most sensitive and water dependent stages requiring critical decision-making. Farmers indicated that information on rainfall amount and distribution is also relevant in decision-making on fertilizer use. Information on rainfall distribution informs adaptive decision-making on the timing for fertilizer application. The amount of rainfall shows intensity for which farmers could consider in determining when to undertake their activities.

f. How to harvest rice

A sense of rainfall cessation based on forecast is required for choice making on what method to use in harvesting. Combine harvesters are mostly used cessation is anticipated to delay. An early cessation affords the use of manual labour in harvesting.

4.4.3.2 Information needs, institutional uncertainty and adaptive decision-making

In a similar vein, respondents indicated what information could improve adaptation to institutional uncertainty conditions within rice farming systems. Although, hydro-meteorological information is not the only needed information, farmers indicated that it is relevant in pursuance of other relevant information relating to land use and water management.

a. Cultivate rice inside irrigation scheme with defined rules

Farmers also require information on land lease arrangements to deal with associated uncertainty due to flexibility in rules within the irrigation scheme. For non-resident farmers who do not own permanent plots within the scheme, making such information available will considerably inform their decision-making. Leadership of the irrigation scheme should aim to collate and publish such information during the pre-season period to better position prospective farmers as part of their pre-season preparations.

b. Prepare land based on practices

Land clearance using labour is also a traditional communal practice common in study communities although this is currently not done in an organised way. Essentially, labour arrangements will be better coordinated when structured and communicated. A good step will be to make information on who is willing to engage in labour arrangements available so farmers can better mobilise themselves in shared support arrangement for mutual benefit.

c. Plant seeds considering practices

Non-resident farmers although forming a minority group amongst rice farmers operating within communities studied indicated that receiving information on rainfall distribution is necessary for investment decision-making pertaining to rice. A greater insight on the hydrology of the dam also contributes to certainty of supplementary irrigation being possible and hence the pursuit of irrigated rice farming as an agenda.

d. Choose harvesting method informed by practices

As indicated during land preparation, harvesting also involves labour arrangements and hence the need to attempt making such information available so as to deal with uncertainty as to rules of engagement which equally affects farmer decision-making.

Table 4.2: Adaptive decision-making and farmer information needs

Stage	Decision	Logic	Uncertainty	Adaptive Choice	Non-Adaptive choice	Information needs
Pre-Season	What crop to cultivate	Consequential	Substantive: -Rainfall onset and distribution	***Multi-crop***	-Grow rice only -Grow other crops only	-Rainfall onset, amount and distribution -Hydrological flow -Rainfall probability
	Cultivate rice both within and outside the irrigation scheme	Consequential		***Cultivate rice both inside and outside***	-Only inside -Only outside	
	Cultivate rice inside irrigation scheme with defined rules	Appropriate	Institutional: -Land lease conditions	***Plant rice under defined land user arrangements***	Plant rice when convenient	-Land tenure -Land lease arrangements
Land Preparation	How to prepare land for cultivation	Consequential	Substantive: -Rainfall amount and distribution	***Choose clearance method based on forecast***	-Use tractor always -Use bullock powered cart always -Use Manual labour always	-Rainfall onset, amount and distribution - Rainfall probability
	Prepare land based on practices	Appropriate	Institutional: -Suitability of method	Adopt method employed by most farmers at any point	***Use manual labour always since it's a traditional method***	-Communal rules -Communal labour practices
Planting	When to plant rice	Consequential	Substantive: - Rainfall probability -Rainfall amount and distribution	***Vary planting date***	-Maintain particular planting date	-Rainfall amount and distribution - Rainfall probability
	What variety to plant	Consequential		***Choose rice variety based on forecast***	-Plant short term variety always -Plant long term variety always ***-Plant variety based on market***	
	When to Plant seeds	Consequential		***Choose planting method based on forecast***	-Use broadcasting method always	

					-Use dibbling method always -Nurse and Transplant always	
	Plant seeds considering practices	Appropriate	Institutional: -Communal labour arrangements	Adopt planting method employed by other farmers at any point	***-Adopt regular practice of broadcasting***	-Communal arrangements on shared support
Weed Control	How to control weeds	Consequential	Substantive: -Rainfall amount	***Apply pre and post emergent weedicides***	Apply pre-emergent weedicide only	-Rainfall amount
Fertilizer Application	How to fertilize soil	Consequential	Substantive: -Rainfall amount and distribution -Rainfall probability	***Apply compost and compound fertilizers***	Apply compost only	-Rainfall amount -Rainfall distribution -Probabilities
Harvesting	How to harvest rice	Consequential	Substantive -Cessation of rainfall	Choose method based on forecast	***-Use combine harvester always*** -Use manual labour	-Cessation of rainfall
	Choose harvesting method informed by practices	Appropriate	Institutional: -Communal labour arrangements	Adopt method employed by other farmers at any point	***Use manual labour always since it's a traditional method***	-Communal practices

**Decisions in bold are most common amongst farmers*

4.5 Discussion

This study focused on establishing how uncertainty is accounted for and what logics are evident in in farmer adaptive decision-making in rice farming systems. Study findings as earlier discussed point to the significance of hydro-meteorological information for adaptive decision-making. Other scholarly works such as Adiku and Stone (1995), Chaudhury et al. (2012) and Jost et al. (2016) point to farmer need for hydro-meteorological information in Ghana. In this section, we discuss the implications of study findings on conceptualising adaptive decision-making and situate the research in empirical evidence on the subject in farming systems. We also discuss the implications of the findings on meeting information needs of farmers.

The study findings establish that both logic of consequentiality and logic of appropriateness are evident in farmer adaptive decision-making as Kristensen and Jakobsen (2011) identified in their study of decision-making amongst dairy farmers with factors such as identity and risks shaping farmer adaptive decision-making. Other scholarly works like Roberts (2015) and Qamer et al. (2019) confirm that farmer adaptive decision-making follows an intentional process of identifying alternatives and estimating outcomes amidst information uncertainties which is fundamental in the logic of consequentiality. There is also the evidence of adaptive decision-making underpinned by the logic of appropriateness as long as rules continue to change in a given context (see Karami, 2006).

A major outcome of this study is that forecast information must also encompass institutional uncertainty within farming systems (see also Nakasone, Torero, & Minten, 2014; Ozowa, 1995). Hence information service providers aiming to provide relevant hydro-meteorological information to deal with substantive uncertainty must also aim at addressing institutional uncertainty to enhance information uptake and impact through adaptive decision-making.

The study establishes that the logic of consequentiality and logic of appropriateness can be explored in decision-making theory especially at the farm level in understanding how institutional and substantive uncertainty is managed in adaptive decision-making. Both logics present a deeper interpretation of how adaptive decision-making occur rather than just measuring the point to which one particular decision is adaptive or otherwise. They provide interpretation for farmer behaviour as studied in other contexts (see Alarcon, Wieland, Mateus, & Dewberry, 2014; Singh et al., 2018).

The study highlights that not only does substantive uncertainty inform adaptive decision-making but institutional uncertainty as well. Findings include the fact that variation in rules over time create institutional uncertainty which farmers have to manage. Nyamekye et al. (2018) also established this relationship showing how governance arrangements informed adaptive decision-making in rice farming systems in the Kumbungu district. It is worth noting that making information available on rules as and when they change is a necessary step to managing institutional uncertainty.

We propose that further studies be undertaken in locations where information needs identified here can be also accounted for and what substantive and institutional uncertainties farmers in those contexts have to deal with. Furthermore, it will be important to establish in other circles which of the two logics of decision-making studied here is evident in farmer adaptive decision-making. Lastly, research further explore how both institutional and substantive uncertainties can be accounted for in the design of climate information services especially in the context of Sub-Saharan Africa.

4.6 Conclusion

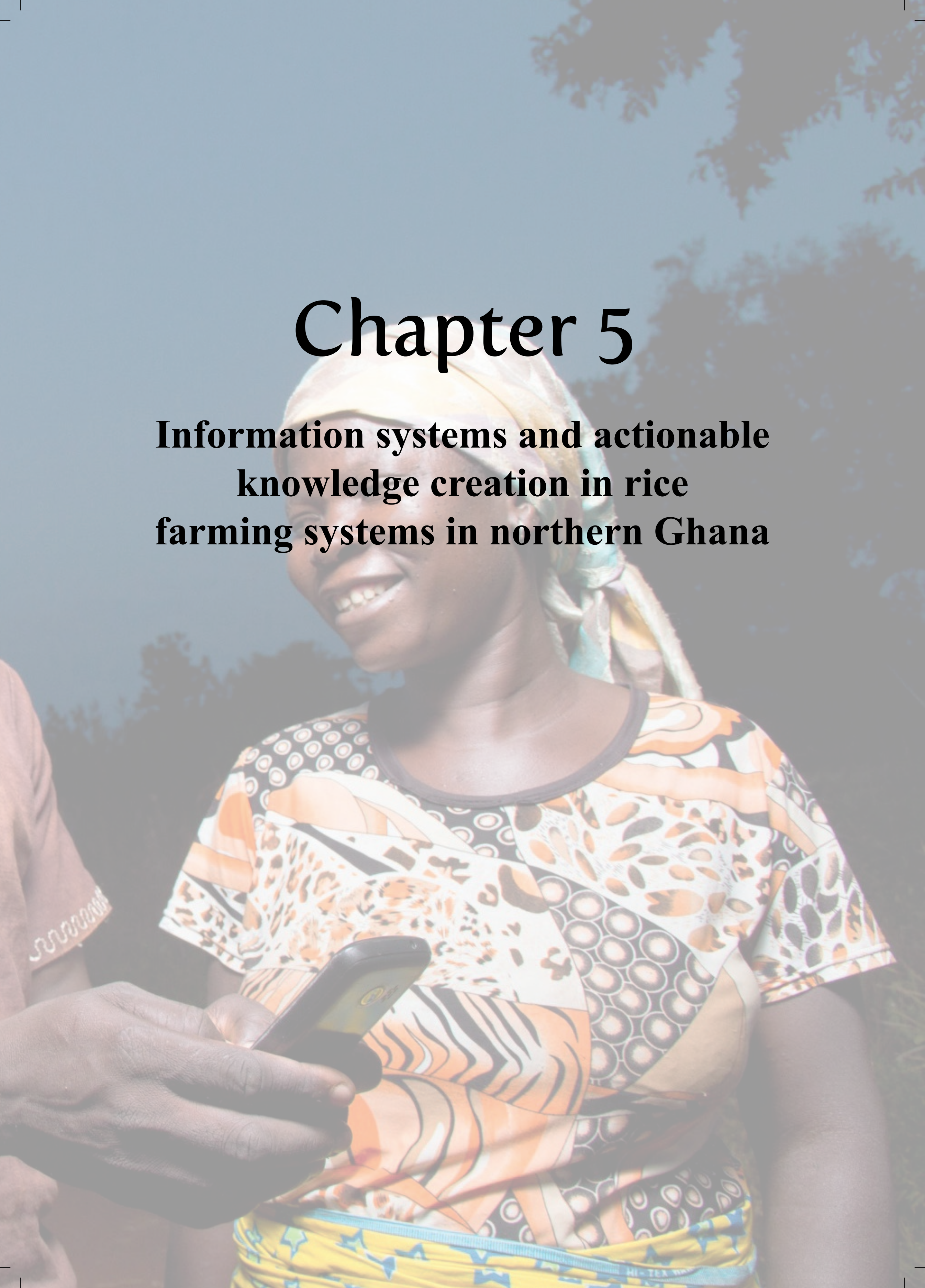
This study highlights that hydro-meteorological information is significant in managing uncertainties in rice farming systems although it is not the only critical input. The paper also points to the existence of uncertainty about rules, alternative choices and their outcomes which rice farmers must manage. The outcomes of the study also affirm that adaptive decisions occur in a thought process underpinned by both logics of appropriateness and consequentiality. However, it can be concluded that uncertainty varies depending on what farming system and structures are set up as well as the degree to which these structures evolve due to change in social and environmental systems. The study also provides further insight into farmer information needs to address uncertainty in adaptive decision-making. This paper contributes to the conceptual debate on how adaptive decisions occur and the underpinning logics of thinking. In a nutshell, the paper provides empirical evidence in northern Ghana emphasising the information-uncertainty-adaptive-decision-making relationship in rice farming systems.

Acknowledgements

The team is thankful to the EVOCA programme for the funding. We are equally grateful to farmers and the management of the Bontanga Irrigation Scheme and farmers.

Chapter 5

Information systems and actionable knowledge creation in rice farming systems in northern Ghana



Abstract

Information systems contribute to information provision and actionable knowledge creation in farming systems. In Northern Ghana, rice farmers interact with information systems through various media to access agricultural information for their decision-making. Of interest here is the degree to which knowledge derived from such interaction is actionable by farmers. Using an exploratory design, the paper addresses the overall question: what information systems are currently providing agricultural information to rice farmers, and to what extent does this result in actionable knowledge? Using Kumbungu District in Northern Ghana as the case study, 99 rice farmers from nine communities were engaged in interviews and focus group discussions. Information systems identified were Mobile-based-only Platforms, Commercial Radio, Community Radio, and Farmer-to-Farmer. The study examined knowledge actionability by assessing the salience, credibility, and legitimacy of knowledge created from farmer-information system interactions; and it revealed that Farmer-to-Farmer systems contribute most to actionable knowledge creation. Mobile technology as a mode of engaging farmers and transmitting agricultural information emerged as the most desirable for information exchange because it eliminated geographical barriers and facilitated reach. We conclude that systems integration and local actor participation are essential for maximising knowledge creation in information systems.

Published as: Nyamekye, A. B., Dewulf, A., Van Slobbe, E., & Termeer, K. (2019). Information systems and actionable knowledge creation in rice-farming systems in Northern Ghana. *African Geographical Review*, 1-18.

5.1 Introduction

Agriculture in developing countries is vulnerable to numerous environmental conditions such as weather variability, water scarcity, and land degradation (Nyadzi et al., 2018; Nkegbe, Abu, & Issahaku, 2017; Regmi & Paudel, 2017; Mechlem, 2004). Small-scale farmers mostly have to deal with complexities associated with climate variability (Deressa, Hassan, Ringler, Alemu, & Yesuf, 2009; Thomas, Twyman, Osbahr, & Hewitson, 2007). In Ghana, the Northern Savannah region is highly characterised by drought and erratic rainfall consequent to high temperatures and low precipitation (Laube et al., 2012; Armah et al., 2011). Low technology adoption and use make it even more difficult for small-scale farmers to maximise productivity on their farms (Akudugu et al., 2012; Conley & Udry, 2001). Rice farmers are amongst the most vulnerable group of farmers because of their reliance on rain to meet water needs (Nyamekye et al., 2018).

Discussing the role of technology in environmental governance, Mol (2006) introduces the concept of informational governance to refer to the idea that information (and informational processes, technologies, institutions, and resources linked to it) fundamentally restructures processes, institutions, and practices of environmental governance in ways different from those of conventional modes of environmental governance. Here, information is not only a conduit but also a resource with transformational power. Informational governance is dependent on environmental information generation, transmission, access and application with ICT support. The informational governance concept has been further applied in environment and sustainability literature (Soma, Termeer, & Opdam, 2016; Lehtonen, Sebastien, & Bauler, 2016; Termeer & Bruinsma, 2016; Hoefnagel, de Vos, & Buisman, 2013). In the context of agriculture, a positive correlation has been identified between homegrown technological solutions and complex problem management (Juma, 2015; Muriithi, Bett, & Ogaleh, 2009). Technological solutions designed to support information collation and use have gained prominence, with a proliferation of information systems (Hounkonnou et al., 2012; Nikkila, Seilonen, & Koskinen, 2010). In Ghana, rice farmers find themselves in an information environment in which public and private, ICT-based and non-ICT-based systems all play a role

(Posthumus, Aarnoudse, & Stroek, 2013; Dittoh, Van Aart, & De Boer, 2013). Being in a web of information systems presents opportunities, but, for informed decision-making, farmers must make sense of the information communicated.

To investigate when and how information from these different systems contributes to farm decision-making, we espouse on the concept of actionable knowledge. Actionable knowledge is knowledge that leads to immediate progress on a current assignment or project (Cross & Sproull, 2004); knowledge that is 'pragmatic' (Carlile, 2002), 'transforming' (Carlile, 1998); or 'usable' (Lemos & Dilling, 2007). Kirchhoff et al. (2013) point to a persistent gap between information production and use and hence the need to distil, both theoretically and empirically, what could constitute actionable knowledge in a given context. To study actionable knowledge in relation to information systems, the concept needs to be further refined. We do so by translating three key factors that have been shown to be relevant at the science-policy interface in farming decision-making: salience, credibility and legitimacy (Cash et al., 2003). We explore how these apply to the scientific and indigenous knowledge produced in rice- farming systems. The study addresses the overall question: what information systems are currently providing agricultural information to rice farmers, and to what extent does this result in actionable knowledge? In this paper, three specific questions are addressed in answering the overall question: i) Which information systems provide agricultural information? ii) How do information systems enable actionable knowledge creation? iii) Which information systems contribute most to actionable knowledge creation?

5.2 Conceptual framework

Informational governance conceptually provides a lens to discuss the transformative power of information. Mol (2006) highlights not only information, but also other factors such as informational processes, technologies, institutions, and practices in informational governance. Informational governance focuses on two interrelated processes: i) steering through information and ii) changes in information flows affecting governance. Mol (2006) draws from Castells' (1996) 'information economy' to discuss the role of information in economic processes, specific forms of social organisation in information generation, processing, and transmission, as fundamental sources of productivity and power.

Rather than unpack the black-box of the technical design of information systems, we investigate how these systems enable information collation and interactivity towards knowledge creation for decision-making. Acknowledging the difference between data, information and knowledge and applying the concepts differently, we define data as facts or numbers; information as processed data communicated with meaning; and knowledge as applicable information (Kettinger & Li, 2010; Benjamin Martz Jr & Shepherd, 2003; Alavi & Leidner, 2001). We operationalise information as the immediate output of information systems based on data collated and processed. We understand knowledge as the outcome of the cognitive process of making information relevant and involving further interaction between end-users of information and systems. Thus, we interpret the process as beginning with data entered into information systems from which information is produced, channelled, and subsequently incorporated into relevant knowledge that may be actionable for decision-making (Lemos, 2015).

Cross and Sproull (2004) posit that information seekers do not only strive to obtain input from providers, but also go through a process of constructing an understanding based on social and physical circumstances. Similarly, Dewulf et al. (2005) highlight that part of the question of knowledge actionability lies in for 'whom' that knowledge is actionable or has 'implementable validity'. Cash et al. (2003) identify three key characteristics of the knowledge-creation process in making information useful: salience, credibility and legitimacy. For these authors, salience refers to scientific information being made responsive and context-sensitive to decision-makers' needs; credibility means that information is accurate, of high quality, and scientifically valid; and legitimacy refers to information produced in an open and unbiased process. Although Cash et al. (2003) do not conclude that the three aforementioned factors constitute how information translates into action and use by decision-makers, the three factors are strong indicators of what could drive information uptake. Some authors postulate that salience is a critical factor if knowledge is intended for decision-making (Clark et al., 2016) and that transparency about the uncertainty of knowledge increases its credibility (Steingrover, Geertsema, & van Wingerden, 2010). Kirchhoff et al. (2013) argue that knowledge production moves from a low (production to increase fundamental knowledge) to a high (production to solve societal problems) point in the space of user participation as users of knowledge become active agents. These authors refer to scientific information rather than including indigenous information in their discussion on knowledge.

In studying rice-farming systems in Ghana, we expand on Cash et al. (2003)'s definitions of the three factors (salience, legitimacy, credibility) to account for contextual factors within which rice farmers operate in Northern Ghana. Indigenous knowledge has been accounted for as applicable knowledge institutionalized in local settings and based on environmental indicators (Chand, Chambers, Waiwai, Malsale, & Thompson, 2014; Kaniki & Mphahlele, 2002). Particularly, our (re)definition considers both scientific and indigenous information that guides farmers' actions. We define salience as locally relevant, timely, and relatable scientific and indigenous knowledge; credibility as knowledge that is trustworthy and can be based on scientific evidence or trust in the experience (indigenous knowledge) of fellow farmers; and legitimacy as scientific and indigenous knowledge produced in a fair, balanced, and transparent way. We thus define actionable knowledge as indigenous and scientific knowledge that is locally relevant, trustworthy, and produced in a fair, transparent way. Knowledge that is actionable should translate into uptake and use in decision-making. Thus, the definitions of these terminologies shift the focus from just information to how the farmer-information system interaction produces knowledge for uptake. Hence, information is not the only defining factor. With the availability of indigenous and scientific knowledge, we operationalise the actionability of knowledge as based on one knowledge system or a complement of both. An element of continuity is established through the application of knowledge and the provision of feedback in the information-knowledge-decision making system (see Figure 5.1).

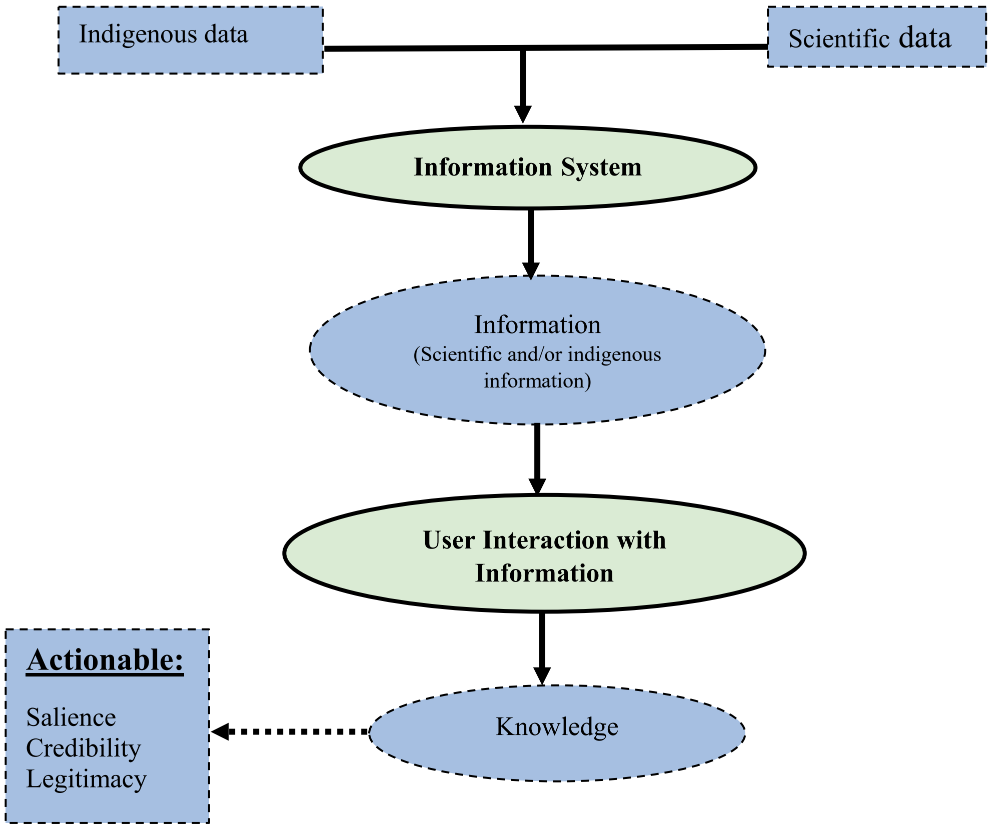


Figure 5.1: Conceptual framework of the study

5.3 Research methodology

5.3.1 Research design

The study adopts an exploratory design (Kumar, 2019; Maxwell, 2012; Kothari, 2004) to gain insights into how information systems make information available and how user interaction with information produces actionable knowledge in rice-farming systems. An exploratory approach is espoused to enable an in-depth understanding of variables in the contextualised study essential for validating scientific conclusions (Jebb et al., 2017; Stebbins, 2001).

5.3.1.1 Data collection and analysis

The study involved interaction with selected farmers within the Kumbungu District (see Figure 2) where farmers experience water stress throughout the season (April-November, 2017). Researchers engaged farmers from nine communities within the district: Sakuuba, Dalung, Kusibo, Yipelgu, Kpegu-Bieggu, Wuba, Voggu, Tibung and Kpalsegu. Twenty-seven farmers (three from each community) were engaged through direct interviews using interview guides over the period (see appendix 5a). Furthermore, three focus group discussions (FDG) (Parker & Tritter, 2006) were held at the onset, midway, and end of the season with selected actors in each community (see appendix 5b). Community leaders (chiefs, assembly members, unit committee members, etc) were also engaged in interviews (see appendx 5d). Power play was managed as most chiefs and assembly members were also farmers and hence not a substantive impact of data quality. Thus the strategy of engaging farmers and community leaders allowed for a comprehensive discussion of key issues bridging boundaries between socio-cultural conditions and information and knowledge creation. Observations were also made of how farmers went about information access and use (see appendix 5e). In all, ninety-nine (99) farmers participated in the study.

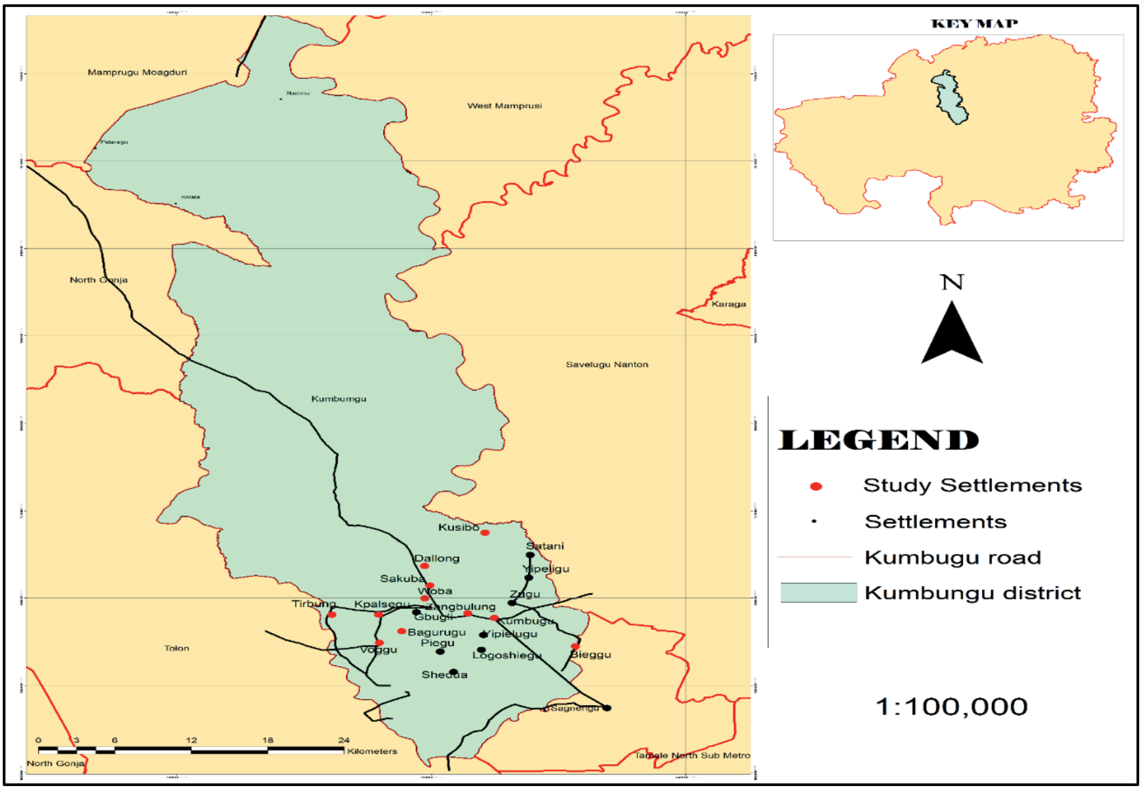


Figure 5.2: Map showing sampled communities in Kumbungu district

Key actors within public and private institutions were also interviewed (see appendix 5c) including the Ghana Irrigation Development Authority, Department of Information of the Regional Office of the Ministry of Agriculture, Ghana Meteorological Agency (GMet), Savannah Research Institute, Dalung Radio, Savannah Radio, and the District Agricultural Development Unit.

Data analysis was undertaken in two stages. The first stage involved cleaning the data from interviews and FGDs. Audio recordings from interviews were transcribed. Field notes were also edited and organised (Maanen, 2011; Wolfinger, 2002; Sanjek, 1990). Data editing entailed reviewing responses to questions as captured and ensuring clarity of thoughts, replacement of shorthand notes with full expressions, and clarifying of constructs and sentences (Dey, 2003; Miles, Huberman, Huberman, & Huberman, 1994).

Table 5.1: Degree to which information system enabled actionable knowledge creation

Criteria/ Score	Most enabling	Very enabling	Moderately enabling	Somewhat enabling
Salience	System provides most locally applicable agricultural information and creates support for local knowledge creation even at farm level	System provides locally applicable agricultural information but not much platform for transformation into localised knowledge	System provides agricultural information, but not necessarily local, and limited opportunity to create localised knowledge	System provides agricultural information, but not necessarily local, and least opportunity to create localised knowledge
Credibility	System always supports the creation of contextually valid knowledge for farmer uptake	System supports to a greater degree the creation of contextually valid knowledge for farmer uptake	System supports the creation of contextually valid knowledge for farmer uptake	System supports somewhat the creation of contextually valid knowledge for farmer uptake
Legitimacy	System creates the opportunity for highest participatory knowledge creation	System creates the opportunity for a greater participatory knowledge creation	System creates the opportunity for some participatory knowledge creation	System creates the opportunity but not much for participatory knowledge creation

The second stage was a thematic analysis, which sought to interpret data in relation to key themes of interest. Themes included i) information system characteristics, ii) Information flow and actionable knowledge creation, iii) knowledge actionability. Analysis deducing the results on information systems identified relatable expressions such as mobile technology, radio systems, communication channel, and information transfer, amongst others. For actionable knowledge, expressions such as trust, useful, transparent, open, true, local, indigenous, scientific were used to guide the analysis. The degree to which information systems enabled actionable knowledge creation was further interpreted in relation to the criteria presented in Table 1. To score and estimate actionability, outcomes of responses from individual interviews and FGDs were examined. The interpretation of actionability was based on how information systems were perceived to be playing roles in creating salient, credible or legitimate knowledge from both scientific and indigenous information and data. Farmers were asked to consider how these reflect in existing systems. A content analysis enabled the researchers to classify the degree to which a component of actionable knowledge was reflected within a particular information system. A summary of the methodology used in the study is presented in Table 5.2.

Table 5.2: Research methodology

Research question	Research methodology	Sampling method	Themes of analysis	Data Analysis
Question 1: Information systems and information gathering	Interview (individual/institutional)	Purposive sampling	-Types of information systems -Information type	-Transcription of recordings -Editing of field notes -Content analysis
	Focus group discussions	Purposive sampling	-Information gathering process -Information translation process	
Question 2: Systems and actionable knowledge creation	Interview, focus group discussions	Purposive sampling	-Knowledge creation process -Participatory engagement processes	-Content analysis -Transcription of recordings -Editing of field notes
Question 3: Actionability of knowledge			-Actionability of knowledge	

5.4 Results

5.4.1 Information systems providing agricultural knowledge

The study identified four types of information systems: Community Radio, Commercial Radio, Mobile-based-only platforms, and Farmer-to-Farmer. Although these systems had similarities, there were clear differences in their set-up. Each information system also engaged end-users differently in information provision and interaction towards creating actionable knowledge.

a. Community radio

Community Radio is an integral part of the information set-up at community and district level. Community Radio such as Simli Radio operates from Dalung with a mission to create a platform for information sharing and discuss issues relevant for local economic development. Targeted listeners are community members within the Kumbungu District, and about 70 percent of activities focus on the local agricultural economy. The radio is managed by inhabitants with a human resource capacity of about 10 people, mostly volunteers. Programmes are broadcast in Dagbanli (90%) and English (10%). Programme plans are designed and periodically updated throughout the year in response to demand and funding. Transmission takes place via Frequency Modulation through radio systems. Agricultural information is gathered from indigenous and scientific sources and disseminated to farmers by radio.

Community Radio contributes to actionable knowledge creation relevant for decision-making. Firstly, farmers are consulted directly during radio programmes for relevant data such as predicted seasonal conditions based on traditional indicators such as movement of clouds, ants, and temperature. Community Radio programme hosts compare this with scientific forecasts provided by institutions such as GMet and the Ministry of Agriculture. Deliberations in the studio involving hosts and experienced farmers further allow for knowledge synthesis based on information received. Discussions begin with special signature tunes[6] to attract listeners' attention. Experienced farmers are engaged at this stage in studio panel discussions to further interpret information towards the production of actionable knowledge during special transmissions,[7] although emerging knowledge is not farm specific, crop-specific agronomic advice is sometimes provided. For example, rice farmers benefit from knowledge on how forecasted seasonal rainfall conditions could affect rice cultivation; or farmers are advised by the in-studio panel as to when to prepare their lands for early or late rains and what

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[6] Example: 'Dandi kugmani kambong –lana' which means 'the one who buys is not equal with the one who produces/farms'.
[7] Entitled *Best Farmer Programme*.

varieties to cultivate. In-studio panel discussions continue throughout the season providing relevant information. Drama is used in some instances to communicate information deemed relevant at particular junctures. During the programme, farmers can phone in and contribute to discussions. Communicating in Dagbanli makes it easier for farmers to interpret new knowledge and increases the extent of actionability or uptake.

b. Commercial radio

Commercial Radio stations are mostly set up with a regional or national rather than a community or district focus. Programmes cut across current affairs, which can be social, political, or environmental. Savannah Radio, a subsidiary of the Ghana Broadcasting Corporation (GBC) set up to disseminate information in the northern zone of the country, is an example of Commercial Radio. Programmes are broadcast by the station in English, Gonja and Dagbanli, the major languages spoken within the zone. The station, given its scope of transmission and status as a public entity, benefits from partnerships with development organisations implementing programmes within the region. Interactions with the programme's director revealed that only 10 percent of the station's programmes focus on agriculture. Furthermore, of its daily operational hours, only four hours are presented in the local languages (2 hours each in Dagbanli and Gonja). Partners sponsoring agriculture-related programmes include the United State Agency for International Development (ADVANCE programme), Farm Radio, and some agricultural service providers. Private individuals dealing in agricultural inputs also support agriculture-related programmes.

Commercial Radio also provides agricultural information and platforms for knowledge exchange and framing towards providing actionable knowledge. Programmes have limited agricultural content because of the scope of activities run by the radio stations. Savannah radio, for instance, dedicates only 4 hours a week to agriculture programmes. Any extra agriculture programmes aired are sponsored and tailor-made depending on the sponsor's interest. In some instances, willingness to pay is no guarantee that a programme will be aired because there are numerous traditional programmes that the radio stations must consider and choose from. Broadcasting agricultural programmes for only four hours a week means that farmers can only access weekly information relating to their practices. Agricultural information ranges broadly from weather and seasonal forecasts for the region to information on input suppliers in the regional capital. This platform provides less opportunity for in-depth discussion. Phone-in sessions during in-studio discussion are limited to 15 minutes. The limited time allotted for agriculture programmes affects the degree to which hosts and in-studio panels can engage farmers for more locally contextualised input in discussions. Listeners are provided with information on fertiliser and weedicide types and application methods. Programme formulation is thus mostly top-down, and farmers are perceived as listeners only. Regional market information is also communicated during the harvesting period. This sometimes proves useful for farmers to decide on when to harvest their crops.

c. Mobile-based-only platforms

Mobile-based-only platforms, including ESOKO, MTN, and Vodafone, also play an important role in information service delivery. These operate from set-ups outside the region and disseminate relevant information to farmers via mobile technology through Short Message Services (SMS) and Interactive Voice Response (IVR), with fewer face-to-face interactions. Farmer clubs have been created as part of the set-up enabling interaction between and amongst farmers for free as part of club membership. SMS is packaged in English and thus farmers in some cases rely on their children, educated family members, or literate farmers to make sense of information received as information is communicated in numbers and texts and not graphics. Farmers can dial assigned short codes to place calls directly to interact with operators of these platforms. About 80 percent of farmers interviewed either owned mobile phones or had at least one family member who owned a phone through which they could access information. Although mobile technology ownership is high, farmers have yet to benefit from its huge potential in the agricultural space. Periodically, Mobile-based-only operators call farmers directly, especially at the beginning of the season as part of data collation.

Mobile-based-only Platforms provide pre-season forecasts directly to farmers through their mobile phones in both voice and text formats. Farmers who are signed up to farmer clubs formed by Vodafone receive free tailored voice or text messages. Registration to join a farmer club involves stating the preferred language of communication. Farmers are thus able to understand voice messages sent to them. ESOKO partners with Vodafone to disseminate information on seasonal forecasts and varieties of crops to cultivate. With the platform allowing free calls between club members, farmers have the opportunity to deliberate on what is communicated to them. Farmers can have follow-up consultations with Vodafone using a short code (550) known club members. Farmers are able to consult ESOKO on all networks (short code 1900). The interaction allows for the creation of actionable knowledge given locally observed indigenous information and knowledge and expert interpretations mostly informed by scientific information. Farmers are thus able to obtain actionable knowledge over the farming season to inform their decision-making.

d. Informal farmer-to-farmer systems

Farmer-to-Farmer systems are framed around communities' existing social structures. They comprise mostly unstructured social gatherings for face-to-face interactions within open spaces in communities. Communication is usually in Dagbanli, in mostly a male-dominated gatherings in the late afternoon almost every day throughout the year. In a few cases women meet to deliberate on the side. Experienced farmers in the main drive the discussions. The stage opens with salutations asking about health and well-being. As most farmers practise multi-cropping or mixed farming, discourse is not usually crop focused. Experiential knowledge, observed conditions, and predictions all inform discourse in this case. Younger farmers defer to older ones to share their experiences. Key questions are posed, such as: What will the rains be like this season? How do we secure farm inputs? How will this season fare in comparison with last season given observed factors? How do we share labour efforts?. What crops and varieties will be best to cultivate in this season? Expressions sometimes involve community-specific locally coined names and words for crops and practices. With farmers joining in and moving out of gatherings, discussions usually continue till late in the evening.

Reflections during Farmer-to-Farmer gatherings continuously improve available agricultural knowledge. In gatherings that are mostly unstructured but guided by social constructions of engagement and interaction, farmers periodically connect and consciously or unconsciously formulate knowledge that drives action. The framing of knowledge directly related to practices and observations contributes to actionable knowledge upon which farmers can act on. Farmers with questions receive the best input from more experienced farmers who equally understand the soil type, disease characteristics, and safe practices in the community context. Younger farmers thus obtain trustworthy knowledge and are able to consult other farmers within the community at an opportune time. For example, rice farmers who cultivate similar varieties continuously interact with their neighbours and share knowledge on observed conditions and the best water management and farm maintenance practices to adopt, including knowledge on tried and tested weedicides and pesticides. This process continues over the season, allowing validation of experiential knowledge that becomes actionable for the next step towards a productive season.

5.4.2 How information systems create actionable knowledge

This section presents findings on how each independent information system fits into the broader network of systems framing knowledge with reference to farmer and system interactions. Rice farmers within the study area interact with all information systems identified, depending on which medium the farmer owns or can access. The information systems are characterised broadly as engaging farmers in gathering similar information and knowledge content, although through different media.

The network of information systems as a single unit thus further enables actionable knowledge creation in rice-farming systems, although this is not consciously structured and regulated. For instance, farmer engagement with Commercial Radio, Community Radio, and Mobile-based-only platforms provides them with insightful information that also guides discussion and actionable knowledge creation in Farmer-to-Farmer systems. For example, experienced farmers who act as panellists in Community Radios like Simli in

Dalung also partake in meetings held in communities as part of Farmer-to-Farmer interactions. As indicated by one farmer in Biegu:

We listen to radio for relevant agricultural information every day. When we meet with other farmers within the community, we discuss what such information means for our farming practice for the season. Out of this discussion, complementing and contrasting views emerge, which also helps in concluding on the way forwards as to what knowledge is best and must be adopted. Some farmers amongst us also serve as panellists on radio and provide us with insightful feedback when related to our farm practices.

Thus, Farmer-to-Farmer systems serve as the point for final deliberation, considering available agricultural information, which can be scientific or indigenous. Actionable knowledge here is thus informed by knowledge emerging from other systems. Similarly, in airing their views during phone-in sessions on the radio, farmers make reference to the actionable knowledge that emerges from Farmer-to-Farmer interactions to support their arguments. Thus, the creation of locally relevant knowledge in a transparent and trustworthy way is best attained in Farmer-to-Farmer systems.

5.4.3 Information system contribution to actionable knowledge creation

Given the existence of a network of information systems, actionable knowledge creation is not limited to a particular system, as farmers engage with all systems identified within the study area. However, as shown in Table 5.3, the degree to which information systems contribute to actionable knowledge creation varies. It is essential to identify which system contributes most to actionable knowledge creation in order to inform discussions on information uptake and the key factors that are significant in ensuring uptake.

Overall, Farmer-to-Farmer systems emerged as enabling most the creation of actionable knowledge, followed by Community Radio, Commercial Radio, and Mobile-based-only platforms. Farmer-to-Farmer systems provide the most apposite opportunity for farmers to access local agricultural information easily relatable to their practices and food systems. Contextually valid knowledge is also created with specific outcomes on what and when to implement at farm level. As there are no barriers to participation in discussions, actionable knowledge is finetuned in terms of its salience, credibility, and legitimacy. Community Radio is the second platform that contributes most to actionable knowledge creation. Although Community Radio does not allow similar room for discourse and participation as Farmer-to-Farmer systems, it strongly enables the creation of actionable knowledge highly applicable at community and farm level. Commercial Radio systems and Mobile-based-only platforms contribute least to actionable knowledge creation. Neither system creates much room for continuous validation of knowledge and the provision of timely localised knowledge valid at farm level. Thus, although most farmers have access to mobile phones, their potential has yet to be maximised, especially on Mobile-based-only Platforms. In Table 5.3, we present in qualitative terms the extent to which information systems enable actionable knowledge creation in rice-farming systems.

Table 5.3: Capacities of information systems to create actionable knowledge

Information system / **Dimension**	**Farmer-to-farmer**	**Community radio**	**Commercial radio**	**Mobile-based-only**
Salience	Most enabling	Very enabling	Somewhat enabling	Moderately enabling
Credibility	Most enabling	Very enabling	Moderately enabling	Somewhat enabling
Legitimacy	Most enabling	Very enabling	Moderately enabling	Somewhat enabling
Actionability of Knowledge: Farmer-to-Farmer systems contributed most to actionable knowledge creation by enabling interactivity and informed participatory process of knowledge creation.				

5.5. Discussion

Information systems currently enabling actionable knowledge creation are numerous and have different characteristics. The degree to which these information systems enable actionable knowledge creation in rice-farming systems also differs. Information systems that are highly participatory and interactive help greatly to produce actionable knowledge. Here, we discuss such systems and identify lessons for the design of information services in rice-production systems.

5.5.1 Towards conceptualizing actionable knowledge

In our interpretation of actionable knowledge, we explore the factors of salience, credibility, and legitimacy. A thrust of our research is that actionable knowledge is context dependent (see also (Brunet et al., 2018; Geertsema et al., 2016; Zakaria & Nagata, 2010; Okigbo, & Igboaka, 2008; Meinke et al., 2006). Secondly, actionable knowledge constitutes a question of process and content framed around local and external conditions. Although Cash et al. (2003) amongst others (see also Dilling & Lemos, 2011; Feldman & Ingram, 2009; Meinke & Stone, 2005) focus on scientific information and how that can be made relevant, our approach identifies two types of information as established in other works (see Nyasimi et al., 2017; Gilles & Valdivia, 2009). Our study establishes the existence of both process and content questions (see also Ha et al., 2008), indicating the need to study not only the 'what' of information but also the 'how' in knowledge discussions. Our study points to a transitioning from information to knowledge to decision-making in making information applicable (see also Aker et al., 2016). Also, when actionable knowledge is being created from information, uncertainty must be discussed, given that change is continuous and thus the actionability of knowledge is tied to time and change in environmental and socio-cultural conditions. (Eernstman & Wals, 2009) affirm this by asserting that knowledge systems are not static.

Actionable knowledge can result from more than one knowledge system. Other scholarly works acknowledging this phenomenon express it in terms such as hybrid knowledge (Pauli, Barrios, Conacher, & Oberthur, 2012) and integrated knowledge (see also Restrepo, Lelea, & Kaufmann, 2018; Kniveton et al., 2015) pointing to the strength in complementary actionable knowledge rather than only indigenous independent knowledge (see also Dujardin, Hermesse, & Dendoncker, 2018; Akullo et al., 2007; Mbilinyi, Tumbo, Mahoo, Senkondo, & Hatibu, 2005; Altieri, 1996; Veraart, Klostermann, van Slobbe, & Kabat, 2018; Biggelaar, 1991).

Furthermore, studying and interpreting actionable knowledge in the ICT context requires the pursuance of system questions about these integrative platforms and their framing in the context of other environmental and social conditions in the current information age. We discuss this in the next section with reference to our findings, amongst others.

5.5.2 Improving actionable knowledge creation: a systems perspective

Earlier works suggest that farmers decide on what information to adopt depending on what information system is involved (see Adegbola & Gardebroek, 2007; Moser & Barrett, 2006). Although the factors of trust and interpretation are significant here, our study points to a basic fact that farmers do not interact with a single information system (see Figure 5.3). Farmers interact concurrently with multiple information systems, hence the actionability of knowledge is a question of the whole. Cash et al. (2003) indicate the need for information to be made salient, credible, and legitimate, but there is also need for a criterion that allows the monitoring of how the different information systems jointly enable knowledge creation for use by decision-makers (see Figure 3). We thus propose that considerable attention be paid to the degree of systems integration as an indicator of how information systems enable actionable knowledge creation. We define systems integration as *the degree of differences or commonalities between information systems in terms of structure, function and approach to user engagement, information provision and how this translate into actionable knowledge creation*. In the case of organisational data management, Fong (2006) mentions schema integration and data integration as methods through which conflicts in data can be managed towards improving information provided. The Unified Multi-Channel Service Model cited by Zhang et al. (2016) in their study of information dissemination models in China is typical of a formal system regulated by a formalised institution to engage multiple models in a single system. In farming systems however, the absence of a single regulatory body garnering private and public efforts at information dissemination leaves actionable knowledge from a systemic perspective to the farmer. This thus suggest the need for institutions to attempt to engage both public and private information system operators in a conscious integration process for end-users like farmers to be able to benefit significantly and improve actionable knowledge creation. Therefore, in section 5.3, we explore the synergistic opportunities available in the systems we studied to improve actionable knowledge creation from a systems perspective.

Secondly, the process of knowledge creation within farming systems is embedded in socio-cultural community settings. For example, the extent to which farmers interact with information systems in the study area is influenced by how these systems are aligned to traditional ways of information exchange and decision-making. Knowledge towards decision-making is led by men. Thus, although information systems aim to ensure an effective engagement process with end-users, the skewness of interactions and non-sensitivity as to who is involved in decision-making could limit the application of supposed actionable knowledge. Consequently, gender dynamics and information access and actionable knowledge creation amongst rice farmers is a key factor that must be further investigated. With women playing a limited role in information access and use, women farmers, although few, are not only limited in accessing the right information at the right time, but also not usually involved in the knowledge creation process. Thus, we propose that local actor participation be examined in studying how information translates into actionable knowledge for decision-making in the context of information systems. We define local actor participation as the extent to which information systems define roles for local actors permanently or otherwise in the design and operationalisation of information systems. Klerkx et al. (2012) reiterate that farming systems are constructed by farmers, depending on their material resources and structures of which technology is part.

Although Cash et al. (2003) indicate that users' values and beliefs should be considered in legitimising knowledge, we propose that attention be placed not just on users' values and beliefs, but also on defining roles guided by local governance arrangements (see also Termeer, Dewulf, & Biesbroek, 2017). The salience factor significantly determines actionability in farming systems because of contextualised knowledge (see also Dewulf et al., 2005). As discussed by (Geertsema et al., 2016) in their study on ecological intensification in agriculture, stakeholder participation is fundamental to defining what is relevant and actionable. The classification of farmers as 'end-users and information systems operators as producers limits the co-creation factor relevant for producing actionable knowledge. Klerkx et al. (2012) argue for a shift from knowledge development to learning and adaptive capacity framed through collaboration (Kristjanson et al., 2009).

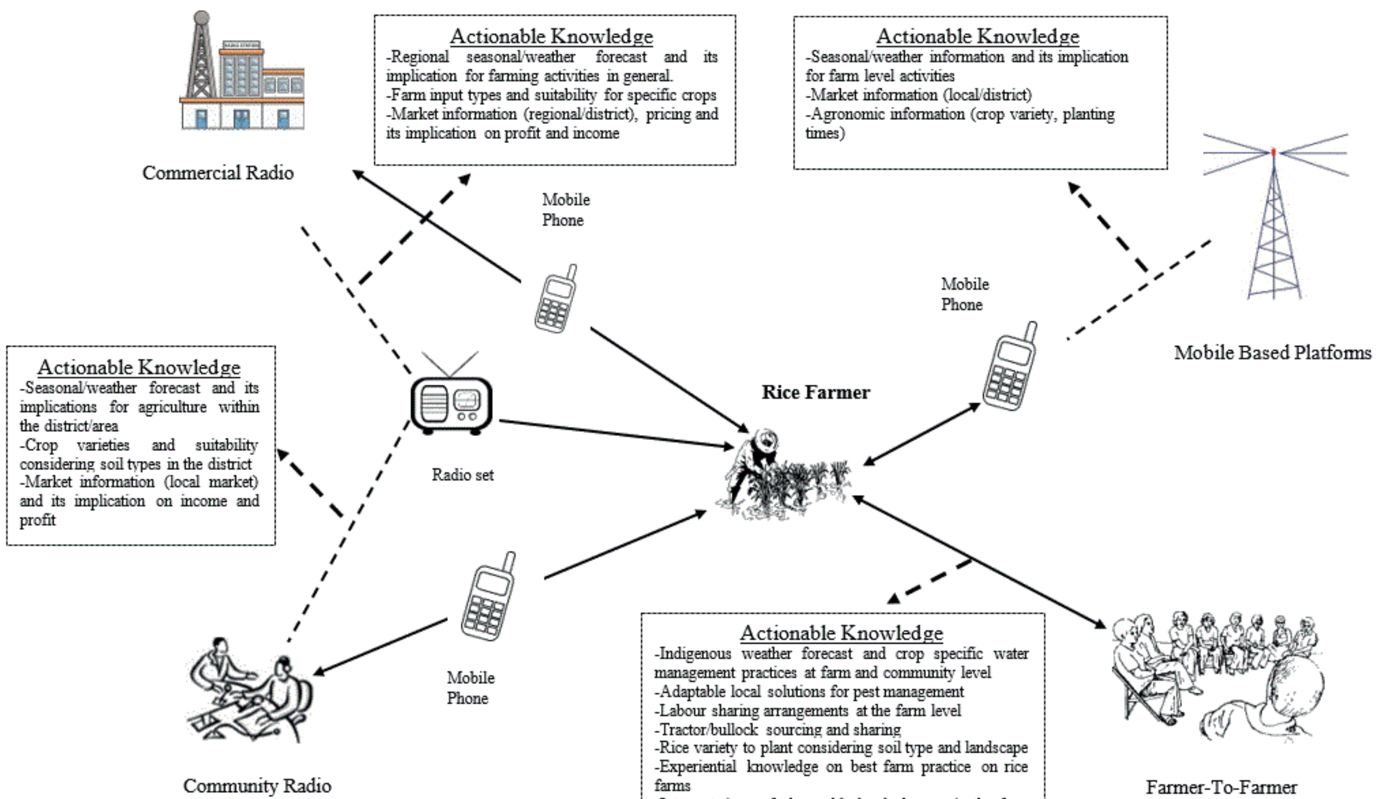


Figure 5.3: Information systems Network and Actionable Knowledge Creation

5.5.3 What opportunities exist for synergies in creating actionable knowledge?

In the current discussion on big data in agriculture, technology provides a great potential for data management and knowledge creation in farming systems (Stephen Sonka, 2015; S. Sonka, 2014). Of the four information systems identified, we discuss potential interdependencies that, when harnessed, could improve knowledge made available for decision-making in rice-farming systems (see Table 5.4).

In discussing opportunities for synergies, Community Radio and Farmer-to-Farmer systems for example, can collaboratively engage farmers within communities in informal meetings as part of knowledge creation processes. (Hudson, Leclair, Pelletier, & Sullivan, 2017) talk about Participatory Radio Programme which they describe as a planned series of radio programs broadcasted to a targeted farming population over a specific period of time. (Diedong & Naaikuur, 2014) point to local ownership as a key challenge of Community Radio systems in Ghana. Evidence from our study buttresses the need to further engage community members directly within their community settings. Operators of Community Radio systems should liaise with leadership of community groups for radio discussions to be organised within local farmer-to-farmer meetings to strengthen the sense of belongingness and ownership.

Etwire et al. (2017) also outline the potential of Mobile-based-only platforms such as ESOKO in agriculture information provision, whilst agreeing, we propose possible opportunities for collaboration between Mobile-based-only platforms and other platforms amongst others as explored in other studies (See Wright, Hammond, Thomas, MacLeod, & Abbott, 2018; Nyadzi et al., 2018; Aker, 2011; Jain, Nfila, Lwoga, Stilwell, & Ngulube, 2011).

Table 5.4: Potential synergies to create actionable knowledge

	Community radio	Farmer-to-farmer	Commercial radio	Mobile-based-only platforms
Community radio		Community radio can pursue an agenda of joining discussion within Farmer-to-Farmer systems to improve their knowledge on issues.	Commercial and Community Radio can organise joint programmes to improve engagement and interactions and knowledge creation.	A formalised arrangement between both systems will ensure the continuous provision of information from Mobile-based-only platforms necessary for knowledge creation at community level.
Farmer-to-farmer	Farmer-to-Farmer systems and Community Radio could collaborate and organize community-based talks that can be directly aired. This will improve knowledge creation and sharing.		Equally, a similar step used in engaging operators of Community Radio could be used to engage Commercial Radio for a greater consideration of interests of farmers' interests during discussions on agriculture.	Mobile-based-only platforms present a potential for Farmer-to-Farmer interactions. Farmers must register to be part of clubs operated on Mobile-based-only platforms.

Chapter 5

Commercial radio	Community Radio could potentially create opportunities for local level engagement and reach by Commercial Radio. This could increase reach and creation of actionable knowledge relevant for farmers at community level.	Commercial Radio might consider identifying areas where Farmer-to-Farmer activities are more structured in communities so they can engage them directly at community level for community-specific actionable knowledge.		Commercial Radio can benefit from information directly from Mobile-based-only platforms through mobile technology. Thus, scientific knowledge can be integrated with local knowledge, making it more actionable.
Mobile-based-only platforms	Mobile-based-only platforms can collaborate with Community Radio in reaching out to communities by integrating them into the information dissemination chain.	Mobile-based-only platforms can increase reach and relevant information gathering by engaging experienced farmers directly.	Mobile-based-only Platforms could reach out to more farmers by engaging Commercial Radio in advertising their services and communicating relevant knowledge created on the platform.	

5.6 Conclusion

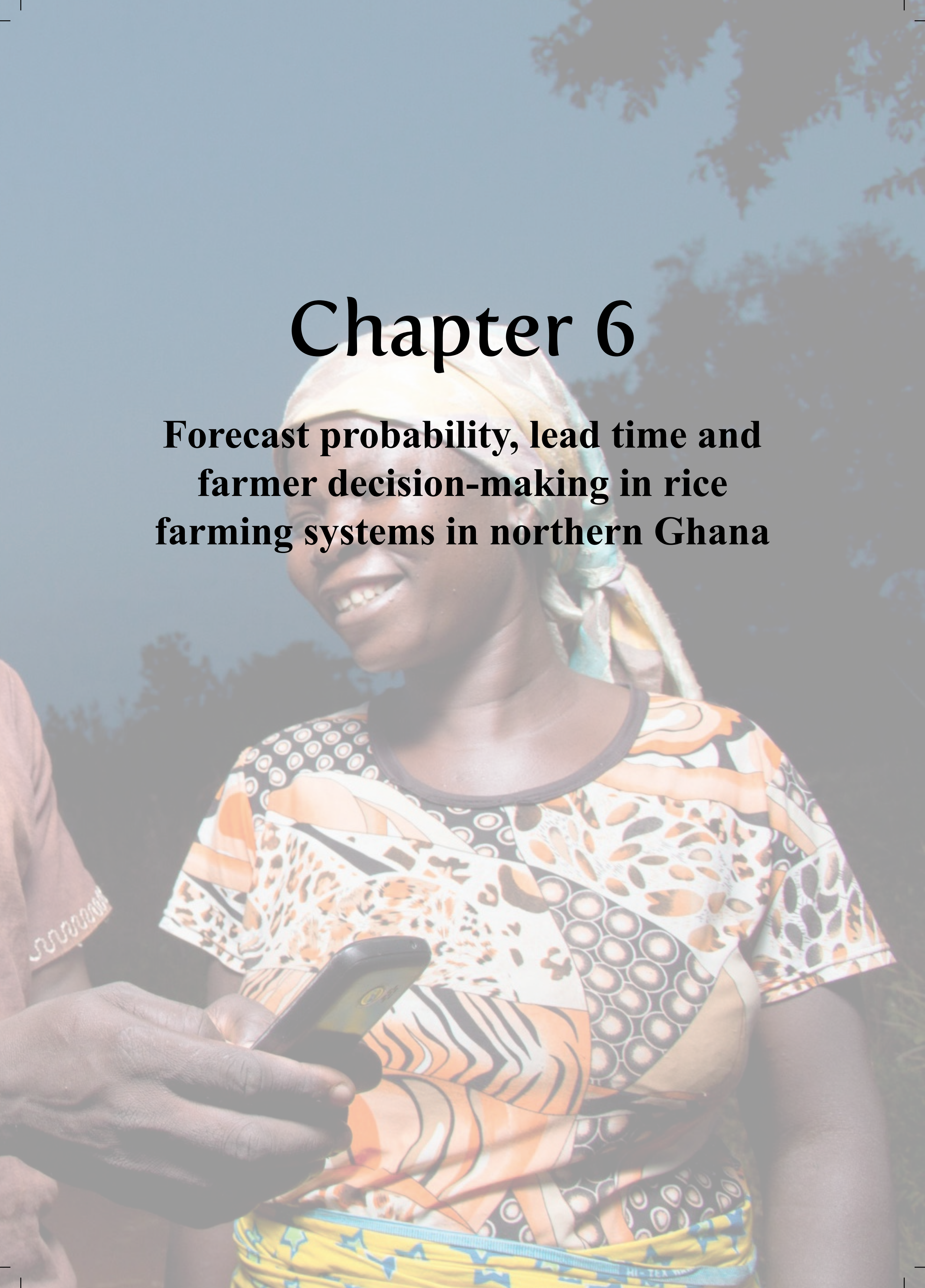
This paper has argued that the role of information systems in rice-farming systems is vital. The study has revealed that information systems function differently in creating actionable knowledge relevant for decision-making. Our study concludes that actionable knowledge is most attainable in Farmer-to-Farmer systems because of the degree of interactivity that occurs within such systems and the extent to which scientific and experiential knowledge collectively informs the process. However, a systems perspective suggests that it is essential to have a framework establishing the synergy between systems and regulating collaborative actionable knowledge creation. The study has also revealed that the process through which information translates into actionable knowledge occurs differently in the various information systems. Nevertheless, mobile phones are instrumentally used in the interactive process of knowledge creation between farmers and information system operators. This is further justified by the argument that local actor participation in the functionality of information systems is crucial. The insights gained from this study will thus be of relevance to the scientific community who aim to understand the pitfalls and success conditions relevant for operating information systems for impact. The most important limitation of the study is its non-consideration of other farmers producing other crops whose experience and input might differ. With most information systems shifting between different crop-farming systems, further studies on how the research questions could be answered in different farming systems could contribute to a more holistic understanding of the wider subject. The study also limits the research to operationalisation of information systems in the context of local governance arrangements, although regional and national levels have an impact on what is workable or not. Further research on multi-level interactions and how they shape communication and information flow is of the essence.

Acknowledgements

The authors are thankful to Wageningen UR for the INREF fund that supports this study. We also appreciate all stakeholders who engaged with us on the field in Ghana. We are also thankful to the reviewers.

Chapter 6

Forecast probability, lead time and farmer decision-making in rice farming systems in northern Ghana



Abstract

Rice farmers in Northern Ghana are susceptible to climate variability and change with its effects in the form of drought, water scarcity, erratic rainfall and high temperatures. In response, farmers resort to weather and seasonal forecast to manage uncertainties in decision-making. However, there is limited empirical research on how forecast lead time and probabilities influence farmer decision-making. In this study, we posed the overall question: how do rice farmers respond to forecast information with different probabilities and lead times? We purposively engaged 36 rice farmers (12 rainfed, 12 irrigated and 12 practising both) in Visually Facilitated Scenario Mapping Workshops (VFSMW) to explore how lead times and probabilities inform their decision-making. Results of the VFSMW showed rainfed rice farmers are most sensitive to forecast probabilities because of their over reliance on rainfall. An increase in forecast probability does not necessarily mean farmers will act. The decision to act based on forecast probability is dependent on which farming stage there is. Also, seasonal forecast information provided at 1 month lead time significantly informed farmer decision-making compared to a lead time 2 or 3 months. Also, weather forecast provided at a lead time of 1 week is more useful for decision-making than at a 3 day or 1 day lead time. We conclude that communicating forecasts information with their probabilities and at an appropriate lead time can help farmers manage risks and improve decision-making. We propose that climate services in Northern Ghana should aim at communicating weather and seasonal climate forecast information at 1 week and 1month lead times respectively. Farmers should also adapt their decisions to the timing and probabilities of the forecast provided.

Manuscript under review: Nyamekye, A. B., Nyadzi, E., Werners, S. E., Biesbroek, R. G., Dewulf, A., Van Slobbe, E., ... & Ludwig, F. Forecast probability, lead time and farmer decision-making in rice farming systems in Northern Ghana. Journal of Climate Risk Management.

6.1 Introduction

Agriculture development in many parts of Africa is heavily impacted by climate variability and change (Benin et al., 2011; Müller et al., 2011). The increasingly unpredictable and erratic nature of weather and climate conditions on the continent is expected to compromise agricultural production and rural livelihoods, especially in smallholder systems with little adaptive capacity (Kurukulasuriya et al., 2006; Cooper et al., 2008). For instance, changes in rainfall onset, duration and cessation have already caused significant adjustment to farming activities (Jotoafrika, 2013; Salack et al., 2015).

Ghana is one example of such countries facing these challenges. An enormous number of its farmers rely solely on rainfall, with less than 1% of land under irrigation (World Bank, 2010; Armah et al., 2011; De Pinto et al., 2012). The Savanna belt of the country is most impacted throughout the year with irregular rainfall, high temperatures and water scarcity conditions(Akudugu M. A. Dittoh S., 2012; Quaye W., 2008; Rademacher-Schulz, Schraven, & Mahama, 2014). The advent of climate variability and change has deepened the woes of farmers who mostly rely on rainfall to meet water needs at the farm level. Irrigated farmers are equally threatened when water levels in reservoirs are too low for irrigation (E. Nyadzi et al., 2018)et al. 2018). As a result, rice production in the north of Ghana is severely impacted due to its high crop water requirement (Kranjac-Berisavljevic & Blench 2003). Yet, rice is a staple food and the need to meet demand under rapidly changing and varying climatic conditions in the area is a major concern(SARI, 2011).

As part of efforts to manage uncertainties, rice farmers seek forecast information on weather and seasonal climatic conditions (rainfall amount, rainfall distribution, onset, cessation etc.) for informed decision-making (Grothmann & Patt, 2005; Nyamekye et al., 2018). Forecast information is expected to improve farmer decision-making by informing choices on how and when to plant, fertilize and plan supplementary irrigation, amongst others (Defiesta et al., 2014; Risbey, Kandlikar et al.,1999).

Currently, farmers in Northern Ghana obtain forecast information from the Ghana Meteorological Services and private information service providers such as ESOKO and Farmerline (Nyamekye et al., 2019). However, the assumption that all seasonal and weather forecast information made available to farmers are useful and used in decision making has been questioned due to a number of challenges (Adiku et al., 2007). First is the timeliness of information. Meteorological information are not made available at the right time could be of limited value to farmers in decision-making. Second is the reliability of meteorological information and how the probability of an event occurring also informs farmer decision-making. Important questions that must be addressed include: How does lead time inform farmer decision-making? At what probability will farmers decide to act or otherwise given meteorological information received? Thus, establishing how farmers make sense of meteorological information considering lead times and probabilities is valuable in ensuring information uptake.

In this study, we build onto the work of Nyadzi et al. (2019) and Nyamekye et al. (2018) who studied forecast information needs and decision making in the Kumbungu district in Northern Ghana respectively. From Nyadzi et al. (2019) we see rice farmers considering hydro-climatic information needs affirming challenges of unreliability and non-applicability of information currently made available especially rainfall. Nyamekye et al. (2018), also explored farmer adaptive decision-making and re-iterate how choice making amongst farmers is highly dependent on the type of meteorological information available. Both studies affirm the need to understand the information-decision-making relationship in rice farming systems in Northern Ghana to improve productivity at the farm level. Building on these studies, we address the overarching question "how do rice farmers respond to forecast information with different probabilities and at different lead times?" To answer this, we pose three specific research questions:

1. How does forecast probability influence farmers' willingness to take decisions?
2. How does seasonal forecast lead time influence farmers' decisions?
3. How does weather forecast lead time influence farmers' decisions?

6.2 Theoretical framework

In farming systems, farmers as decision makers aim to understand complex conditions such as climate variability and change and its consequences on their choices in their effort to maximize utility (Gigerenzer & Selten, 2002; Olsson et al., 2004; Smit & Wandel, 2006; Buytaert et al., 2010; Termeer et al., 2011). Thus, meteorological information as a resource informs decision dynamics through a process of (re)framing to reduce risks (Barnes et al., 2013; Wallace & Moss, 2002). Where available, the degree to which meteorological information, especially on rainfall, is timely and reliable determines farmers' willingness to act and the kind of decisions they take (Verbeke, 2005; Weaver et al., 2013; Dewulf & Biesbroek, 2018; Gbangou et al., 2019). In climate change literature, uncertainty and forecast lead times have been highlighted in bridging climate information usability gaps in decision-making(Podestá et al., 2002; Lemos et al., 2012; Mase & Prokopy, 2014; Roudier et al., 2014).

This study sought to test three hypotheses in understanding the relationship between meteorological information (focusing on rainfall) and farmer decision-making although there are a lot of factors that determine farmer use of meteorological forecast(Vogel, 2000; Ziervogel, 2004). First, that the higher the probability associated with a forecast, the more farmers are willing to act on their decision at every stage of decision-making within the farming cycle. In this case, although the probability of a forecast cannot be 100 percent, farmers irrespective of practising rainfed or irrigated farming will act out their intended decision when rainfall probability is high. Weisheimer and Palmer (2014) opine that probabilistic reliability should be the foremost measure of the 'goodness' of a forecast. Herewith, the 'goodness' of a forecast is a contextual question requiring the positioning of its interpretation in specific farming systems. Letson et al. (2001) concur with reference to their findings on obstacles to greater use of climate information. Langford and Hendon (2013) affirm and buttress how unreliability remains an impediment to the uptake of climate related information.

Our second hypothesis is that seasonal forecast communicated at different lead times has consequences on the choices farmers make in seasonal decision-making. Thirdly, we also posit that weather forecast made available at different lead times significantly drives in-season decision making. Forecast communicated with a 'sufficient' lead time has a positive correlation with productivity (Zinyengere et al., 2011). Seasonal climate forecast has no intrinsic value except for their ability to influence decisions of users (Hammer, 2000). Sub-seasonal-to-seasonal forecasting range seen as 'predictability desert' due to initial difficulties has gained attention in the bid to bridge the gap between weather forecasts and seasonal outlooks (Vitart et al., 2012). Randomizing probability, seasonal and weather information variables in the context of rice farming systems requires holding other conditions (finance, land, labour, etc.) that influence decision-making constant.

6.3 Methodology

6.3.1 Study area

The study was undertaken in the Kumbungu District in the Northern region of Ghana as shown in Figure 6.1. The district, located within the Guinea Savannah agro-ecological zone covers a land area of 1,599km^2 with Kumbungu as its capital. The District shares boundaries to the north with Mamprugu/Moagduri district, Tolon and North Gonja districts to the west, Sagnerigu Municipal to the south and Savelugu Municipal to the east (Abdul-Malik & Mohammed, 2012). Farming is the mainstay of inhabitants cultivating cereals, tubers and vegetables including rice, millet, sorghum, groundnut, tomatoes and pepper. Average annual rainfall is 1000mm with the main cropping season stretching over the period of May to late October (Quaye et al., 2009). The temperature is warm, dry and hazy between February and April. The district is drained by the White Volta and other smaller rivers and their tributaries with most drying up in the dry season. The Bontanga Irrigation Scheme located within the district also supports irrigated farming with crops such as rice and vegetable mostly produced within the scheme.

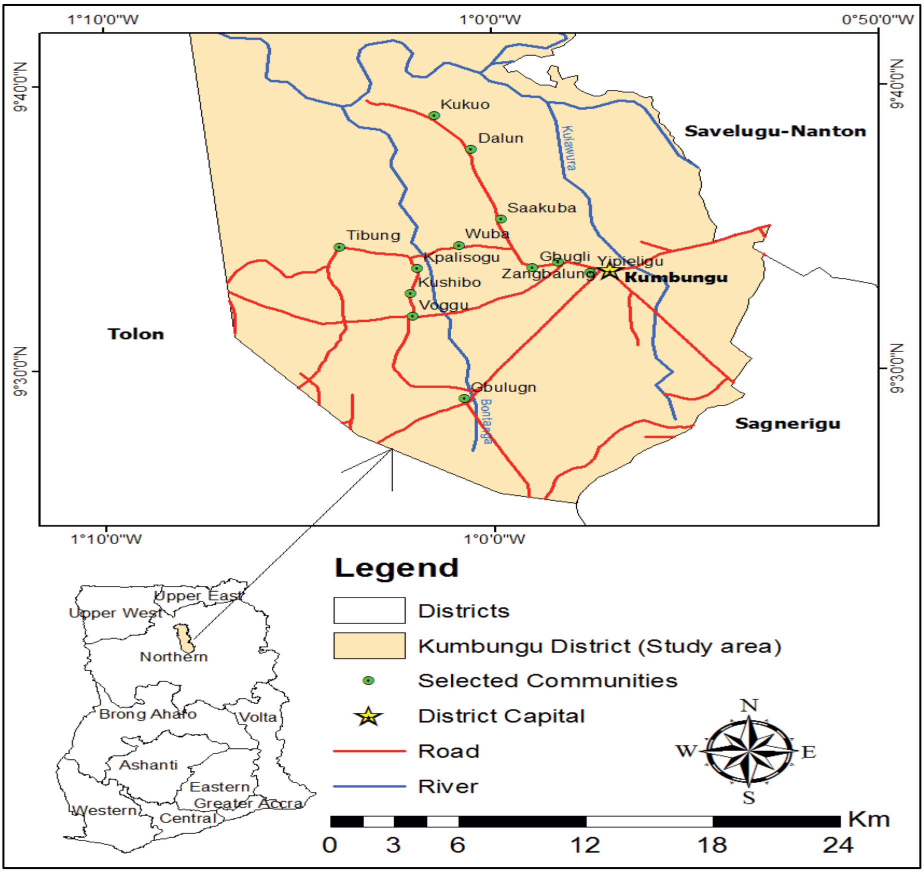


Figure 6.1: Map showing the study location

6.3.2 Research design

Scenario Workshops (SW) have roots in technological assessments and originally designed to facilitate engagement between scientists and citizens in the appraisal of new technologies (Andersen & Jaeger, 1999). SWs have also dominated planning circles for giving a participatory foresight to resource management and also used in engaging citizens in testing technological solutions(Andersen & Jæger, 1999; Mayer, 1997; Rinaudo et al., 2012). The study adopted a Visual Facilitated and Scenario Mapping Workshops (VFSMW) (Hatzilacou et al., 2007; Mexa, 2002) focused on three main groupings of farmers; irrigated, rain fed and those who practised both.

A total of five workshops were organised. The first workshop was a kick-off workshop with the objective to select and familiarise with the participants and explain to them the rationale of the study. The kick-off workshop also aimed at grouping farmers, setting up the environment with the required tools as well as agreeing on dates for the rest of the activities. In addition, rules of engagement were communicated to the participants and opportunities created for questioning and clarifications. The second, third and fourth workshops were the VFSMW specifically focused on engaging different farmer groups directly to test the different information variables and what they mean for farmer decision-making. Here, farmers were given a cardboard and spinning wheels showing the source of information, certainty and forecast lead-times. On the cardboard was a matrix showing the cropping cycle for easy representation and understanding considering literacy levels of the participants. Individually, participant(s) were taken through seven decision points of the cycle (see appendix 6a).

Participant(s) were randomly exposed to three spinning wheels with each wheel focusing on a key information variable (probability; lead time (seasonal); lead time (weather). Each variable also had three main indicators for which farmers were required to indicate what decision they will make considering these indicators. The purpose of the wheel is to allow for randomization of the information to be tested. The fifth workshop was a validation and feedback workshop. At this workshop, preliminary results were communicated and discussed. Participants feedback on key findings were also noted. The process for VFSMW is summarized in Figure 6.2. A detailed manual on design and steps of the VFSMW is presented in appendix 6d.

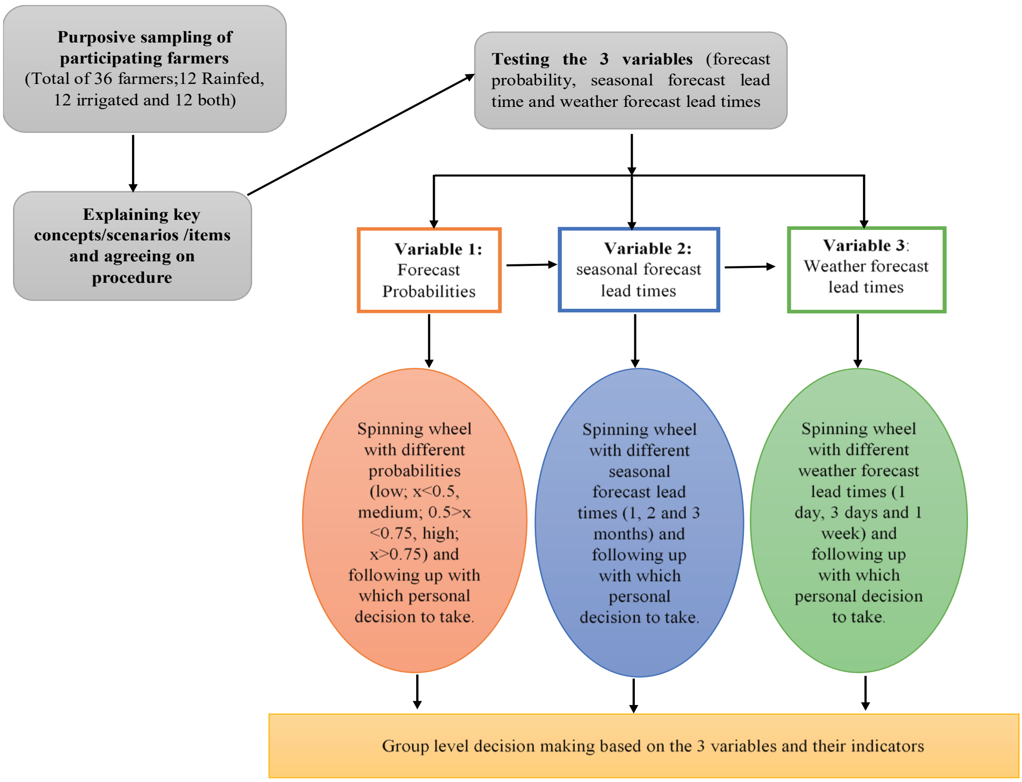


Figure 6.2: Stepwise approach to the VFSMW

6.3.3 Sample and sampling approach

With the support of the leadership of farmer associations and the extension officer in the area, a total of thirty-six (36) rice farmers (3 from each community engaged in either rainfed, irrigated or both) were purposively sampled from 12 different communities for the VFSMW workshops (See Figure 1). The VFSMW was used to test three (3) main variables and twelve (12) indicators fashioned out of research questions. The variables include; (i) Probability of rainfall forecast information for decision-making (ii) Lead times of weather forecast for decision-making (iii) lead times of seasonal climate forecast for decision-making. For each of these three variables, a couple of indicators and their influence on decision-making was established focusing on rainfall and what prevails under normal conditions. Farmers were engaged in what decisions they will take under different scenarios. The experiment was carried out in this order: first, the probability of forecast and farmers' decision-making , secondly seasonal forecast lead times and farmer decision-making and thirdly weather forecast lead times and farmer decision-making.

Variable 1: Probability of rainfall forecast and farmer decision-making

The degree of certainty associated with weather and seasonal climate information is expected to inform farmers' information uptake and adaptive decision-making. Here, participants received information on the probabilities of forecast information categorised as (1) low ($x<0.5$), (2) medium ($0.5>x$ <0.75) and (3) high ($x>0.75$). Interactions were based on the assumption that it will rain but at these different probabilities. For each of these probabilities, we recorded whether farmers would act or not given. We treated the probabilities in each case as the independent variable and the decision "will act" and "will not act" as dependent variables.

Variable 2: Seasonal (rainfall) forecast lead times and farmer decision-making

The timing of information provision at seasonal timescale affords decision-makers, in this case, farmers to have either more or less room in deciding what decisions to take. We deduce which decisions farmers take given different lead times (1 month, 2 month and 3 months) under 'normal' conditions and whether there is a substantive difference in actions adopted by farmers in this regard. The dependent variables in this test were also "will act" and "will not act" and the independent variables were the three lead times.

Variable 3: **Weather (rainfall) forecast lead times and farmer decision-making**

Building on from the rationale behind the testing of variable 2, the participants were exposed to varying lead times of weather forecast information. Here, we tested which decision farmers will take given lead times of 1 day, 3 days and 1 week. Unlike variable 2, the dependent variables in this test were the decision options of farmers and the dependent variables were the three lead times.

6.3.4 Data analysis

We employed both qualitative and quantitative methods in data analysis. The data gathered from the workshop were coded and entered into SPSS version 23 for analysis. The decisions gathered during the workshop were grouped given key expressions and then coded for easy analysis in SPSS. Results of the analysis are presented in frequencies and percentages.

6.4 Results

6.4.1 Forecast probability as a determinant of risk acceptance level

Our study findings point to different sensitivities to probability depending on what activities farmers had to undertake. The study showed a positive correlation between forecast probabilities and farmers' decision to act in the pre-season and planting. It emerged that, as probability increased, farmers were willing to take action on forecast information received (see Figure 6.3A). However, an inverse relationship between forecast probability and decision making was observed during the remaining stages of the farming cycle. Farmers would rather withhold intended action at the point of land preparation, weed control and fertilizer application when the probability of rainfall forecast is high (see Figure 6.3B). Clearly, the aforementioned farming stages are very sensitive to the rains and cannot be favourably completed when rains are expected. For example, farmers indicated that fertilizers do take a while to be absorbed in the soil and undertaking such in the moment of expected rainfall could result in the fertilizer being washed away. Thus, although high probability is a good indicator of rainfall occurrence, it also results in non-action taking as a response.

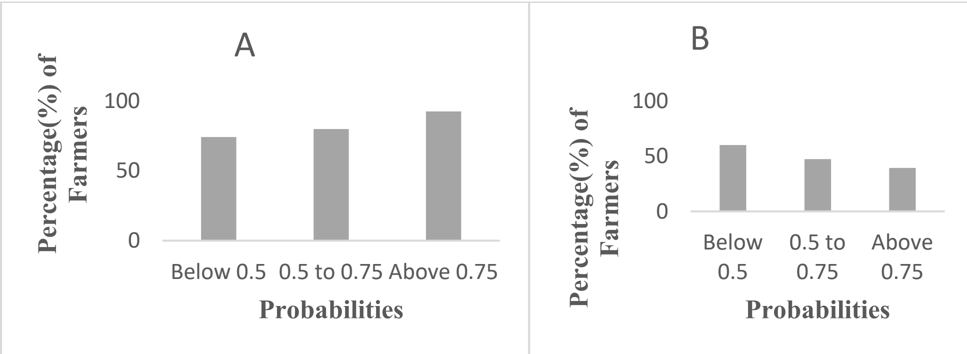


Figure 6.3: The general influence of forecast probabilities on farmers' decision to act (n=36 farmers). [A. Preseason and planting B. Land Preparation,1st and 2nd weed control, 1st and 2nd fertilizer application and harvesting]

A further disaggregation given different farming type showed that irrigated rice farmers and to an extent those who practised both were least sensitive to different forecast probabilities compared to rainfed farmers. For irrigated farmers, this can be alluded to the option of meeting water needs through supplementary irrigation. Farmers who practised both might also have lesser risk since they may still count on their irrigated farms should the rains failed. Rainfed farmers however, remain sensitive because they have no option except to face their lost and thus are sceptical in their decision making.

At the pre-season and planting stages in Figure 6.4A, irrigated farmers will act irrespective of the probability of the forecast information given. More rainfed farmers and both will act given a forecast information with higher probability. However, during land preparation, weed control and fertilizer application forecast with high probability were faced with negated action by all group of farmers (see Figure 6.4B). For example, irrigated farmers will also not fertilize if rainfall expectations are high because will result in washing away of fertilizer as mentioned earlier.

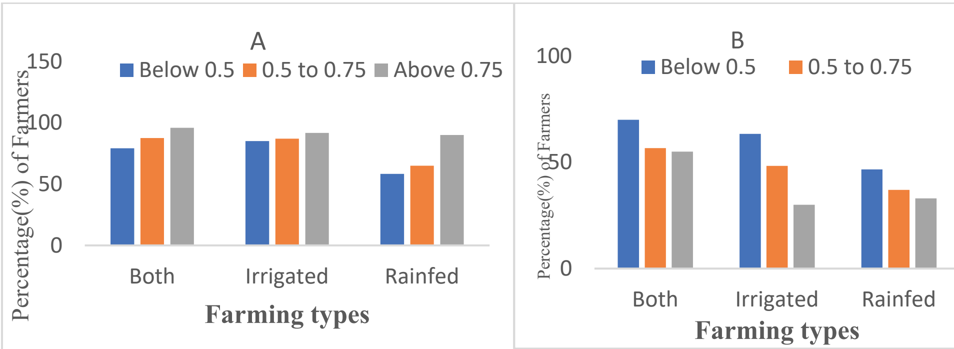


Figure 6.4: The impact of forecast probabilities on different types of farmers' decision to act (n=36 farmers) [A. Preseason and planting B. Land Preparation,1st and 2nd weed control, 1st and 2nd fertilizer application and harvesting]

Furthermore, interaction with farmers at the group level provided further evidence to the results obtained at the individual level decision making. A higher probability (above 0.75) helps farmers in concreting their decision-making through choice making on whether to take action or withhold undertaking an intended activity with the ultimate aim of maximizing yield and productivity. Thus, farmers' respond to communicated forecast probabilities depends on farmers estimated risk aversion. Nevertheless, several external factors including financial capacities and personal attributes (family size, belief, gender) also frame farmer decision-making. Outcomes of group engagement also suggest that uncertainty in forecast information which is currently not communicated to farmers by service providers such as ESOKO and Ghana Meteorological Agency is the reason for non-uptake as compared to lead times.

6.4.2 Seasonal forecast lead time and farmers decision-making

The results of the study showed seasonal forecast provided at a 1 month lead time significantly informed farmer decision-making as part of preparatory arrangements before the season begins. Much also, irrespective of farming type, farmers agree that a lead time of 3 months is of least relevance as the 3 month pre-season period could come with much greater variation in expected seasonal conditions and also the fact that the majority of farmers will do nothing given a 3 month window of opportunity. From the data, there was more agreement between irrigated rice farmers and rainfed rice farmers on how seasonal forecast at different lead times influence their decision-making. This is shown in Figure 6.5 and appendix 6b.

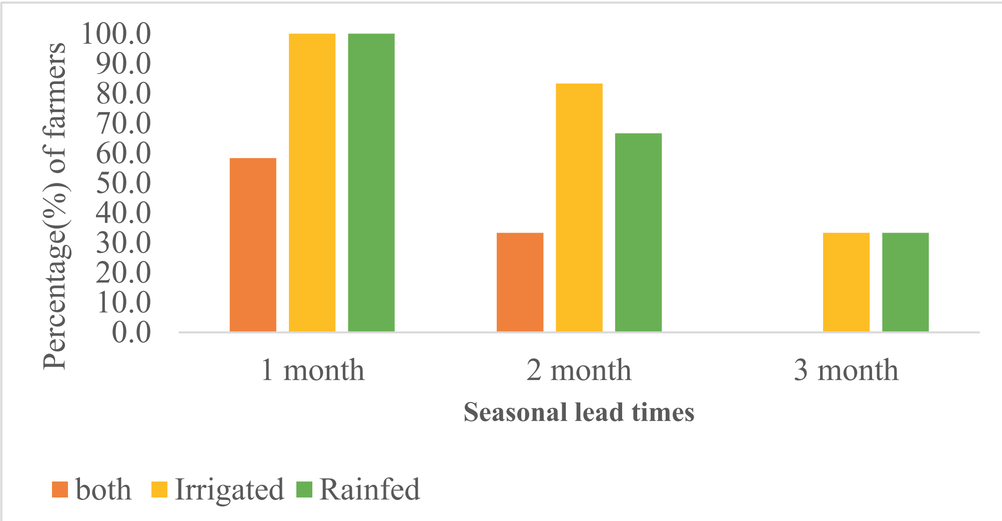


Figure 6.5: Farmers willingness to act given seasonal forecast at different lead times (n=36 farmers) [None of the farmers involved in both indicated they will act on a 3 month seasonal forecast]

Focusing on farming systems dynamics, it emerged that 100% of irrigated and rainfed farmers will act when forecast information is communicated at a lead time of 1 month as compared to those engaged in both (58%). Also, 83%, 68% and 33% of farmers engaged in irrigated, rainfed farming or both respectively confirmed they will act given seasonal forecast at a lead time of 2 months. Forecast information provided at a 3 month lead time is of less relevance to farmers with about 68% of farmers involved in either rainfed or irrigated rice farming confirming they will not take any initiative with such information (See Figure 6.6). All farmers practising both indicated that they will not act on seasonal forecast information at a 3 month lead time as it is too early a period to pursue any farm related activity.

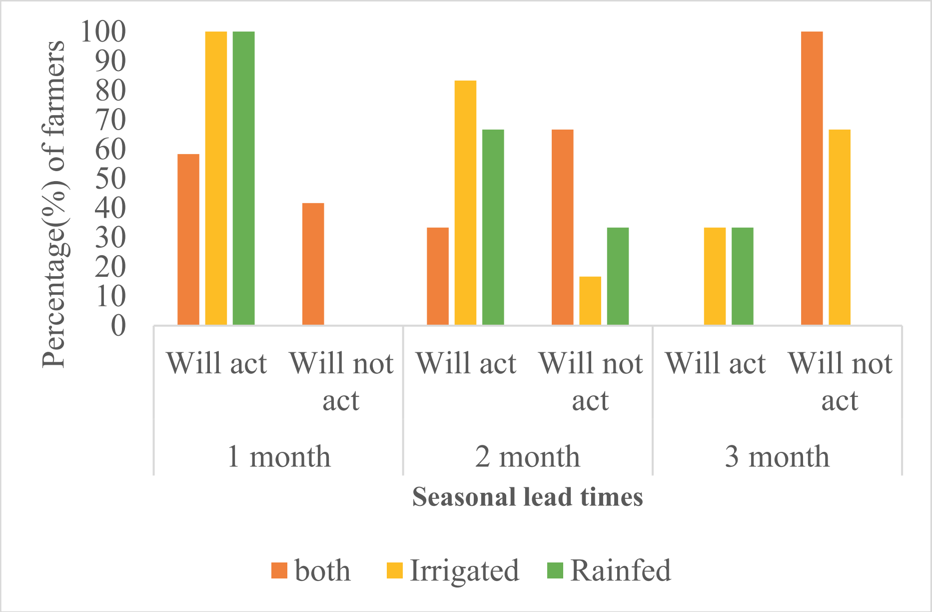


Figure 6.6: Percentage of farmers indicating that they will take a decision to act or not under different seasonal forecast lead times (n=36 farmers).

Further interactions at the group level during workshops showed that although seasonal forecast is important for farmers decision-making, 92% of farmers in all group deliberations confirmed strongly that forecast information at a 3 month lead time is of little relevance for them. Nevertheless, farmers indicated that some important deliberations occur at the household level within this 3 month period. Most of the deliberations focus on financial planning for both farm and non-farm related expenditures such as school fees, medical bills and payment of outstanding loans. Pre-season decisions also entailed arrangements for farm labour and tractor acquisition. However, seasonal forecast presented at 3 months and 2 months lead time were not relevant for such decisions as compared to 1 month with 90% of farmers confirming such.

6.4.3 Weather forecast lead time and farmer decision-making

The results revealed that farmers take different decisions given weather forecast information at different lead times (see Table 6.1 and appendix 6c). At the point of land preparation, 89% of all farmers indicated given rainfall forecast information at a 1 day lead time, they will prepare their lands using a tractor. Similarly, 75% of farmers engaged still indicated they will clear their farmlands using a tractor should they receive rainfall forecast at a 3 day lead time. However, 73% indicated that they will use manual labour to clear their lands when rainfall forecast is provided at a one week lead time.

Regarding decision-making on planting, majority of farmers showed a preference for broadcasting seeds. The findings showed that 89% of farmers will broadcast their seeds when rainfall forecast is provided at a lead time of 1 day. Also, 70% and 64% will broadcast upon receiving rainfall information at a lead time of 3 days and 1 week respectively.

The decision on fertilizer application is one of the most sensitive to water availability conditions. Majority of farmers (97% at 1 day lead time, 83% at 3 days lead time) will apply fertilizer rather after rainfall using placement method and sprinkle in case they intend to apply fertilizer before the rain when such information is communicated. However, given rainfall forecast information at one week lead time, farmers will apply fertilizer by placement. Thus, a 1 week lead time offers much flexibility in decision-making.

The application of weedicide was less sensitive to rainfall with about 92%, 97 % and 100% indicating they will apply weedicide before rainfall when forecast information is communicated at a 1 day, 3 days and 1 week respectively. This is attributable to the fact that farmers only need a few minutes to a couple of hours to complete the task of spraying weedicides although that is also dependent on the size of farmland under cultivation.

The second stage of fertilizer application also pointed to the need for soil moisture or ample time to apply fertilizer before the rains. The results suggest similar practices as the first phase of fertilizer application. Here, 89% of farmers indicated they will apply fertilizer by placement after the rains when forecast information is communicated at a 1 day lead time. Similarly, more farmers (56% and 60%) will prefer to apply fertilizer by placement after rainfall given forecast at a lead time of 3 days and 1 week respectively. Thus, the sensitivity of farmer decision to water availability conditions is more severe at the first stage of fertilizer application than the second. Farmers face a greater risk of crop loss within the period of the first fertilizer application than the second.

Farmers indicated that harvesting is less sensitive to rainfall conditions but more defined by access to harvesting tools and machinery. In effect, given forecast information, 75% of farmers will harvest with a combine harvester at a 1 day, 3 day time and 64% of farmers will use the same method at 1 week lead time.

Indicatively, weather forecast provided at different lead times came with choices farmers found most appropriate that minimise their risk and chances of completing activities at each stage in time. At no point did farmers point to not do anything given forecast at different lead times. Table 1 presents the percentage to which a particular choice was made by farmers at a particular farm stage.

Table 6.1: Farmer decision making under different weather forecast lead times.

Farming stages	**Decision Choice**	***% of Responses (One Day Lead Time)***	***% of Responses (Three Day Lead Time)***	***% of Responses (One Week Lead Time)***
Land preparation	Will clear the land using manual labour	11.1	25	72.3
	Will clear land using a tractor	88.9	75	27.8
Planting	Will broadcast seeds	88.9	69.5	63.9
	Will nurse and transplant seedlings	11.1	16.7	19.4
	Will plant using the dibbling method	-	13.9	16.7
	Will apply fertilizer by	2.8	16.6	47.2

1st fertilizer application	broadcasting before the rain			
	Will apply fertilizer by placement after the rains	97.2	83.4	52.8
Weed control	Will apply weedicide after the rains	8.3	2.8	100
	Will apply weedicide before the rains	91.7	97.2	-
2nd fertilizer application	Will apply fertilizer by broadcasting before the rain	11.1	44.4	36.1
	Will apply fertilizer by placement after the rains	88.9	55.6	60.4
Weed control	Will apply weedicide by spraying after the rain	80.5	13.9	5.6
	Will apply weedicide by spraying before the rain	19.2	86.1	94.4
Harvesting	Will harvest with a sickle	25	25	36.1
	Will harvest with a combine harvester	75	75	63.9

Generally, forecast provided at 1 week lead time better positions, farmers, to decide on acting or not followed by 3 days and then 1 day. Farmers argued that 1 day lead time is too short a period to undertake most farm activities except weedicide application for weed control and broadcasting in the case of planting. For example, providing forecast information 1 day before land preparation and also fertilizer application leaves limited room to adjust decisions. A 3 day lead time, however, offers more time for farmers to act compared to 1 day.

6.5 Discussion

This paper sets out to understand how different forecast sources, lead times and probabilities influence farmer' decision making. We explored this relationship using different information scenarios and groups of farmers within rice farming systems in a bid to investigate how seasonal and weather information could be tailored to farmer information needs in farming systems. In this section, we discuss inferences from our research findings in relation to other scholarly works on addressing weather and seasonal climate information needs in rice farming systems in Northern Ghana.

Firstly, our findings reveal that communicating forecast information with different probabilities in Northern Ghana significantly informs farmer decision-making thereby addressing the research question 1. We, however, reject the first hypothesis that claims that the higher the probability associated with a forecast, the more farmers are willing to act on their decision at every stage of decision-making within the farming cycle. This hypothesis was rejected because framers respond to different forecast probabilities is dependent on the farming type. For instance, there is a positive correlation between increasing forecast probability and farmers' decision to act during pre-season and planting stages. Meanwhile, a negative correlation exists between increasing forecast probability and the decision to act during Land Preparation, weed control, fertilizer application and harvesting. Furthermore, we discover that farmers understood that 100% certainty in weather and seasonal climate forecast information is non-achievable due to the erratic nature of events and are thus adaptive in their response to forecast probabilities. Breuer et al. (2000) and O'Brien and Vogel (2003) concur that the probabilistic nature of weather and seasonal climate forecasts present particular challenges. Hence, for effective use of forecast information, decision-making must take into account the probability of forecast. Also, although all farmers expressed the need to minimize uncertainty, farmer response varied and was dependent on the farming system being practised and the estimated risk that had to be managed. For instance, due to water availability for supplementary irrigation within the irrigation scheme, rice farmers operating within the scheme face lower risk levels and will act even when forecast probabilities are less than 0.5. This was contrary in the case of rainfed farmers. Thus, forecast probabilities must be clearly communicated to farmers.

In communicating forecast probabilities one needs to reflect on the ways in which they are presented. From our experience, using simple graphics with appealing colours to represent forecast probabilities is an effective way of making farmers understand what is been communicated. For instance, each farmer type deals with forecast probability differently and so forecast probability could be communicated based on different types of farmers. Less sophisticated farmers will prefer simpler information. Moreover, how one describes forecast probabilities must fit into the domain of farmers' local knowledge, therefore it is essential to understand how farmers generate and describe probabilities. More so, ascertain whether their personal feelings of risk and vulnerability influence their definition. It is important to also communicate change in probabilities in simple terms and in languages that are best understood by farmers. Further follow-ups on how a change in probability impact farmer decision-making or practices will enhance our understanding of the pros and cons of a failed forecast on farmers' livelihood.

Secondly, the study outcome also confirms a part of our first hypothesis given the findings that given different lead times of weather and seasonal climate forecast, farmers made different decisions. However, not all lead times contribute to a change in decision-making. For example, seasonal forecast information provided 3 months ahead of time is irrelevant in taking pre-season decisions. What is strongly recommended is seasonal forecast information at a lead time of 1 month. In our context, this is the period within which most pre-season arrangements (farm machinery, labour, seeds, etc.) and decisions happen. Crane et al. (2010) following their engagement with 38 farmers in Northern Georgia made similar conclusions that farmers are less likely to rely on seasonal forecast with longer lead time. They acknowledge that lead time must conform to users' needs and priorities. Essentially, the lead time for communicating seasonal forecast must be estimated through the lens of farmers. Similarly, not all lead times for communicating weather forecast information can contribute to informed farmer decision-making (Stone et al., 2006; Mase & Prokopy, 2014) . As evident in our results, activities such as fertilizer application and planting are highly sensitive and difficult to undertake when forecast information is communicated with a 3 day or 1 day lead time. Also, the period of fertilizer application is the most water sensitive stage of the farming season. Thus, a lead time of 1 week offers more flexibility for farmers to react to weather forecast information. This is however of least significance in the context of decision-making on weed control and harvesting.

The use of Visually Facilitated Scenario Mapping Workshops also renders the opportunity to explore how a future functioning hydroclimatic virtual observatory providing farmers with forecast information under different conditions could inform their decision-making. The approach creates a hypothetical environment for establishing farmer response to information from climate services or hydroclimatic virtual observatory as proposed by Nyadzi et al. (2018). Therefore, the results from this exercise could slightly differ from real time events depending on conditions where social and biophysical conditions of farmers could vary. Scenario workshop methodologies originated in technological assessments and were designed to facilitate engagements between scientists and citizens in the appraisal of new technologies (Mayer, 1997; Andersen et al., 1999). We give more of a visual spin to the methodology which can be applied in other contexts in co-production and citizen science experiments on climate services.

Our methodology also had a number of limitations. First, maintaining other external factors (finance and resource availability, etc.) constant could not depict a vivid environment for which farmers make decisions. Results could be different should we consider the interaction of these factors. Secondly, , the experiment focused on rainfall without consideration for other atmospheric variables (temperature, humidity, etc.) which also could have influence farmers' decision outcomes. Hence, a similar study with a broader look at other variables could produce different results in different contexts. Thirdly, our test of focused on farmers decision making under normal conditions performing this experiment under extreme situations could afford the opportunity to analyse comparatively what decisions farmers take under different situations.

In a nutshell, the results of this study have critical implications for the design and operation of climate services particularly in Northern Ghana and also answers our third research question. First, the results confirm that different farm types (irrigated, rainfed and both) in the study area requires forecast information at specific lead times and probabilities. Hence, operators of weather and seasonal climate information services must understand their audience. Also, for effective decision making, farmers have much preference for weather and seasonal climate information at 1 week and 1 month lead times respectively. This means in the provision of information, emphasis must be placed on the quality of forecast information at these lead times in order to meet farmers' needs. This nevertheless is valid in rice farming systems and hence could though hardly vary in other systems. Thirdly, communicating forecast probabilities to farmers is essential. Different types of farmers relate differently to forecast uncertainty or probabilities. Farmers especially those into rainfed farming have little room for taking huge risk and will only use forecast information with higher probabilities. Hence understanding these dynamics can extensively improve acceptance and uptake of weather and seasonal information making climate services more useful and impact oriented.

6.6 Conclusion

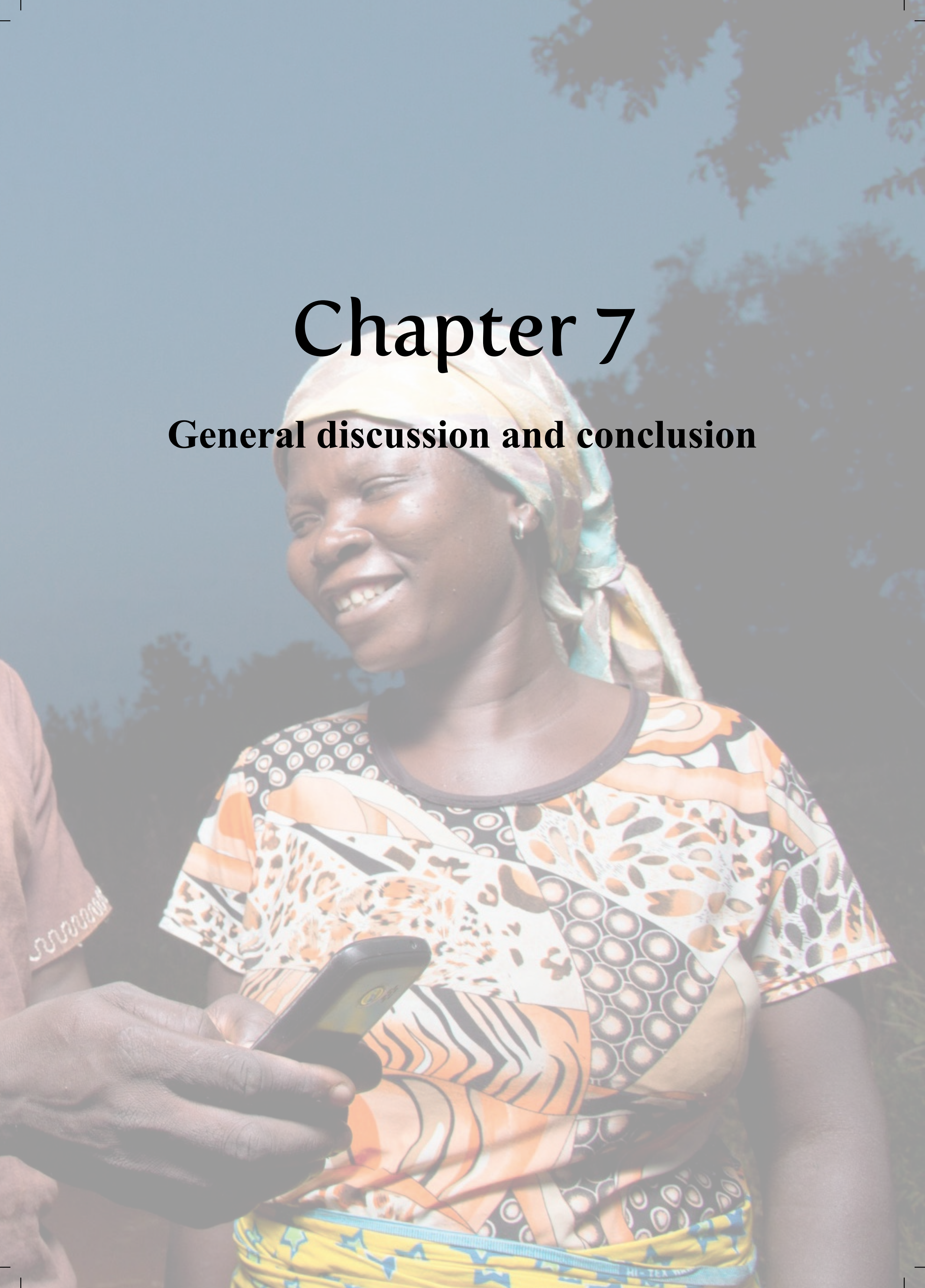
Based on the evidence provided in this study, we conclude that communicating forecast information at the appropriate lead times and probabilities has the potential of making climate services more useful for farmers. More specifically, we discover that, first, an increase in forecast probability does not necessarily mean farmers will act. The decision to act is also dependent on which farming stage there is. Secondly, weather and seasonal climate forecast information at 1 week and 1 month lead time respectively most conveniently informed farmer decision making. Secondly, fertilizer application and planting decisions stages of rice farming are most sensitive to rainfall. Thirdly, irrigated rice farmers have comparatively lower risk level and will act irrespective of forecast probabilities. Farmers should also adapt their decisions to the timing and probabilities of the forecast provided. Finally, user-driven climate services should aim at engaging end-users in the framing of information and content rather than assume the universality of the usefulness of what is presented for uptake.

Acknowledgements

This study is financially supported by Wageningen University (INREF Fund), MDF and KITE-Ghana. The authors are thankful to the management of the Bontanga Irrigation Scheme and rice farmers engaged in the Kumbungu District. We confirm that the authors have no conflict of interest

Chapter 7

General discussion and conclusion



7.1 Introduction

Uncertainty as a result of climate variability and change challenges farming systems to adjust their seasonal and day-to-day decision-making. Climate information systems aim to provide relevant information to support farming decisions, but these information systems are not always available. Where they are available, their impact has often been limited.

This dissertation sought to engage irrigated and rainfed rice farmers, water managers, and other stakeholders in rice farming systems in communities located in the vicinity of the Bontanga Irrigation Scheme in Kumbungu District (Ghana), over four years. The aim was to find out how existing information systems contribute to actionable knowledge creation for decision-making in rice farming and to inform the design of a new generation of climate information systems. In doing so, this dissertation has contributed to debates on information systems, actionable knowledge, uncertainty, and decision-making, as can be seen in Chapters 2 to 6.

Chapter 2 presents a reflection on climate information systems by engaging with existing debates on responsible innovation and environmental virtual observatories (EVOs). The guiding question is: *Which principles could guide the design and operationalisation of climate information systems in rice farming systems in Northern Ghana?* (RQ 1). The study reflects on empirical social and technological conditions identifiable in the study area and what these imply for the design and operationalisation of a new breed of climate information systems. The chapter sets the tone for a deep dive into governance arrangements and decision-making contexts in the study area. It also provides an entry point to the necessity of understanding information systems.

In the studies in Chapters 3 and 4, emphasis is placed on understanding governance arrangements, be they formal or informal, and decision-making contexts by addressing the key question: *How do governance arrangements influence farmer adaptive decision-making given uncertainty and information needs?* (RQ 2). The chapters provide an empirical analysis of governance arrangements and adaptive decision-making (Chapter 3) and an empirical analysis of the role of different decision logics and types of uncertainties in farmer adaptive decision-making (Chapter 4).

From a thorough understanding of the farmers' decision-making context, the studies in Chapters 5 and 6 then interrogate information needs and knowledge creation processes in rice farming systems. The key question here is: *How do existing information systems enable actionable knowledge creation and what information could improve decision-making in rice farming systems?* (RQ 3). Here, I was able to establish what information systems exist, their characteristics, and their role in actionable knowledge creation, borrowing strongly from the work of Cash et al. (2003).

In this final chapter, I seek to answer the research questions by highlighting the empirical outcomes and theoretical contributions of the thesis, but also to contribute to broader scientific debates on these topics. Areas for further research are proposed, and the limitations of the study and how these could have directly or indirectly influenced the study outcomes are outlined.

7.2 Towards a new generation of climate information systems (RQ 1, Chapter 2)

7.2.1 Designing climate information systems in Ghana

For information systems to contribute better to knowledge creation and decision-making, it is necessary to establish how their design can contribute to this objective. Given the current emphasis on digitalisation of the agricultural sector in Ghana, it is timely to address gaps in technical questions regarding the architecture of climate information systems in order to improve the interaction and participation of farmers and other local actors. In Chapter 2, I indicate that, for climate information systems to better support decision-making in farming systems, a new structure must be explored in which different types of data can be collated and actionable knowledge created. The proposed architecture is discussed along three broad lines: data definition; information provision and use; and feedback.

Data definition

The diagnostics in Chapter 2 establish the relevance of both scientific and indigenous forecasts in estimating seasonal and weather conditions. Farmers in Bontanga and its environs rely not only on scientific forecasts received, but also on ecological knowledge using local indicators such as the movement of birds, direction of the wind, movement of ants, amongst others. However, existing information systems mostly do not include this local knowledge in their forecast information. We see a weak collaboration between current information service providers and farmers. Furthermore, the limited engagement of farmers translates into difficulty in managing farmer expectations in the area, with farmers losing trust in information especially when inaccuracies are observed. Also, some farmers perceive that non-timeliness of information and limited engagement of farmers also affect information relevance and uptake for decision-making. Hence, in Chapter 2, I draw attention to the need for a new generation of climate information systems that improve forecast certainty and relevance by combining both scientific and indigenous data in seasonal and weather forecasts, as explored in other contexts (Kalanda-Joshua, Ngongondo, Chipeta, & Mpembeka, 2011; Mahoo et al., 2015; Masinde & Bagula, 2011).

In a study by Kalanda-Joshua et al. (2011), respondent farmers in Malawi indicated that current weather and climate forecasts were not useful because indigenous knowledge is not incorporated into forecasts that are made available. Grothmann and Patt (2005) found that farmers' acceptance of seasonal climate forecasts increased when they were provided as part of local indigenous climate forecasts. Hence, Chapter 2 of this dissertation proposes that, in the definition of data, farmers should be engaged in data collection using indigenous forecast indicators either independently or with the support of extension officers. Because of farmers' low literacy levels, the data collection process should be closely monitored to minimise errors. Here, mobile technologies could be used to engage farmers in data collection using simple interfaces of imagery and a binary logic of a 'yes' or a 'no' response.

In addition, the design of climate information systems must not only account for biophysical changes but also recognise social and cultural transformations

(Agrawal & Perrin, 2009; Vaughan & Dessai, 2014). Although social and cultural conditions might not be directly included as datasets, interaction between scientists and farmers must involve further probing how these factors could be dependent variables and deterministic of what data or information could be of relevance and eventually used in decision-making.

Information provision and use

In Chapter 2, the diagnostics show that farmers in the Bontanga area have difficulties interpreting information received via information systems given their low literacy levels and challenges in interacting with technology. Meteorological information provided is not always in the local dialect and hence, for the non-literate farmer population in the area, further consultation is needed to make sense of what is received. Secondly, most farmers in the Bontanga area use simple-feature phones or non-smart phones, which are only SMS and voice message compatible. It also emerged that information systems operate independent of each other. Nevertheless, the diagnostics also outline some opportunities that could be leveraged to increase information access and use in the study area. For example, there currently exist agri-focused radio stations such as Radio Tongu and Simli Radio, which provide agricultural information to farmers in local languages. Furthermore, there is a high rate of radio listenership in communities within the study area and across the region. Such potential presents the opportunity to collaborate in the provision of meteorological information. The results in Chapter 2 refer to the communal practice of informal social meetings amongst farmers that also serve as avenues for information exchange and hence could be leveraged by community radio services.

Given this background, the chapter also discusses how a proposed climate information system could be differently framed whilst capitalising on opportunities and eliminating existing barriers. For this, it is recommended that, when information is being packaged, the architecture must explore the use of more graphics and less text and also seek to adopt local symbols and images that are relatable to farmers. Here, digital technology that can help bridge physical barriers to information sharing and communication must be simple regarding representation and interface to ensure compatibility with most phones owned by farmers. Thus, farmers' ability to decode information from the system and the extent to which feedback from farmers to the system can be decoded are critical in the architecture.

Misaki et al. (2018) concur that a language barrier makes it difficult for farmers to interpret information provided to them through mobile technology. Also, the synergy between both loops is highly dependent not only on the mode or technology used but also on the extent to which co-design is pursued. Thus, co-production must begin with co-design in setting the tone towards enhancing the use of climate information (Bremer et al., 2019; Christel et al., 2018; Tall et al., 2014). Vaughan et al. (2016, p. 2) reiterate the need for an iterative process of co-discovery, co-development, and co-evaluation of climate information systems.

In Chapter 2, I outline possible communication tools and their limitations, given current applications in other information systems. The climate information system architecture must include guidance on how mobile technology, the web, radio, and other non-ICT models can be embedded in the system design (Houghton, 2010; Mittal, 2016). The design process must take cognisance of how these tools can support the content, packaging, and presentation of information and enhance the process of transforming information into relevant knowledge for application.

Feedback mechanisms

Chapter 2 also proposes a two-way communication framework, where the architecture of climate information systems allows for feedback from farmers following the receipt and use of information, expressed through decisions about dealing with uncertainties in seasonal and weather conditions. A supporting finding in a study by Archer (2003) in South Africa confirmed that farmers, especially women, were quick to indicate their preference for a two-way information system that allowed them to ask questions rather than the one-way system used by most information service providers in communicating meteorological information. Hence, I indicate in Chapter 2 that climate information systems should be designed to support interaction in local languages in a continuous interactive feedback process. As much as possible, the iterative process should make room for unlimited engagement to ensure timely responses and reformulation and interpretation of information to make it more applicable in a given context.

> ***Insight:*** *For climate information systems to have impact, they should be user-centred in design, anchored on the principle of interactivity, and fitted into the local context.*

7.2.2 Reflections on the conceptualisation of climate information systems

Climate information systems are extensively discussed in the current literature, using multiple approaches underpinned by theories of decision-making, environmental and business management, technology, and innovation (Feldman & Ingram, 2009; Fraisse et al., 2006). The Global Framework on Climate Services set out by the World Meteorological Agency presents Climate Service Information Systems (CSIS) as the operational core of the framework. The framework highlights the objective of CSIS as the processing and generation of relevant data and knowledge. It also prioritises the timely dissemination of information at all scales (WMO, 2014). The underlying pillars of the framework indicate direct delivery of CSIS product for uptake or through interfaces that seek to integrate the information into end-user decision-making.

The discussion on user-centred design emphasises contextualisation and what that means for the potential of climate information systems (Jancloes et al., 2014; Pulwarty & Sivakumar, 2014; Singh et al., 2018). Vaughan and Dessai (2014) highlight contextualisation and institutionalisation as key for impact. Dutton (2002) contends that weather and climate services are becoming varied thanks to advances in information technology and broader demand. In the agriculture sector, the relevance of forecast information at seasonal and sub-seasonal scales for improving adaptive decision-making – especially at local level – makes it essential to align the constructs in the climate information systems framework in terms of how they respond to the timely processing of data and dissemination of information and knowledge through collaboration or co-production.

In Chapter 2, I discuss the climate information systems framework through the lens of second generation EVOs, which allows for further framing of the concept kick-started by Karpouzoglou et al. (2016a). For this, participation, as a pillar of the climate services framework, is promoted to maximise efforts at knowledge co-creation. Drawing on informational governance, adaptive governance, and actionable knowledge reiterates the significance of aligning the architecture of climate information systems in agriculture with governance as a practice. Hence, expanding the scope of climate information systems to account for not only environmental information, but also social change through governance, enhances their transformative capabilities. Informational governance encompasses not only technologies, but also an appreciation of informational processes, institutions, and resources linked to information. In the framing of their architecture, second generation climate information systems should reflect a scenario where climate information communicated 'becomes a crucial resource with transformative powers for a variety of actors and networks' (Mol, 2006, p. 5).

This dissertation underwrites the conceptualisation of second generation climate information systems with reference to Karpouzoglou et al.'s (2016) argument by adding that information and knowledge processes must be standardised as part of the architecture of climate information systems rather than being perceived as mere inputs or by-products of the process. Such a premise proposes that information with reference to data must be recognised as 'soft' architecture without which climate information systems could contribute less to knowledge creation. I indicate the need for information to constitute not only scientific but also indigenous knowledge to ensure consideration of end-user practices.

I also contend that, in addition to the element of interactivity as postulated by Karpouzoglou et al. (2016a), it is essential to embrace the elements of reflexivity and anticipation (Stilgoe et al., 2013) in unpacking the pillars of adaptive governance. Reflexivity is understood in the sense that developers of climate information systems acknowledge the limits of their knowledge and are mindful that their framing of the problem may not be universally held; hence, what could be treated as data must go through a reflexive process to embrace other perspectives. It also means that forecast information from the system is driven not only by projected change (anticipation), but also by the monitoring of current social-ecological change and how farmers respond (responsiveness).

Designing a second generation information system also necessitates embracing the concept of actionable knowledge and the mindful pursuit of it (Karpouzoglou et al., 2016). Here, there is much reference to participatory methodologies and a bottom-up approach to integrating multiple user needs and local experiences. The framework must interpret actionable knowledge from multiple perspectives, thereby also enhancing the probability of ensuring that reflexivity is built into the knowledge co-creation process. As highlighted in Chapter 2, the architecture of a second generation climate information system must seek also to establish how stakeholder reflexive processes contribute to knowledge formulation (Adams et al., 2015; Brandsen & Honingh, 2016; Meadow et al., 2015; Tall et al., 2014). I make reference to the concept of citizen science as an approach to engage farmers and other actors in climate data collation in second generation climate information systems. Citizen science should be a conceptual overlay in the co-design process or any form of collaborative arrangements in positioning climate information systems in rice farming systems.

In Chapter 2, the dissertation also brings to bear the element of feedback, with the argument that the uptake of information for decision-making creates new knowledge from practice; this is relevant for further understanding change in food systems at farm level. Hence, a feedback loop allows for outcomes of practice to be channelled back into the system as new data. This informs the systemic thinking in defining the architecture of climate information systems (Hewitt et al., 2012; Lourenco et al., 2016; Weaver et al., 2013; Yousefpour et al., 2017).

> ***Insight:*** *The architecture of second generation EVOs has the potential to result in more productive climate information systems.*

7.3 Uncertainty and adaptive decision-making in rice farming systems (RQ 2, Chapters 3 and 4)

7.3.1 Adapting to seasonal and weather variability

Information systems can contribute to adaptive decision-making by providing a measurable indicator of how such systems can improve adaptive governance in farming systems (Gadgil, Rao, & Rao, 2002; Ali & Kumar, 2011). Adaptive decision-making within rice farming systems remains a challenge because of changes in social and bio-physical conditions, and uncertainty about the near future. Chapter 3 of the dissertation shows that irrigated and rainfed rice farmers are amongst the most vulnerable in Kumbungu District because of the changes in water levels in the Bontanga dam and rainfall patterns. It emerged that farmers make decisions about *what to cultivate, how to prepare the land, how and what to plant, how to control weeds, how to fertilise crops, and how to harvest*. The findings in Chapter 3 show that farmer decisions are *most sensitive* to water availability conditions during *planting and fertiliser application*. Farmers adapt during planting by choosing decision options such as varying planting dates or planting only when soil moisture is high (see also Abid et al., 2016). Farmers also operate within a context guided by formal and informal rules that have an impact on their practices and decisions. Effectively, adaptive decision-making in dealing with uncertainties encompasses not only uncertainties about biophysical conditions, but also rules defining interactions and resource use in the Bontanga area.

Hence in Chapter 4, by focusing on two logics of decision-making: the logic of appropriateness and the logic of consequentiality and how these are reflected in farmer adaptive decision-making, the dissertation establishes how uncertainties are accounted for. In Chapter 4, we see farmers taking adaptive decisions by considering substantive uncertainty associated with forecasts received and the consequences of choices. For example, during the pre-season period, farmers have to decide on what crop to cultivate. With reference to the seasonal forecast received, farmers choose between multi-cropping or growing only rice or other vegetables. We observe that the adaptive choice is to multi-crop as a hedge against rainfall onset and distribution varying from the expected. Non-adaptive choices, however, include cultivating rice only or other crops only. Farmer behaviour is a function of attitudes, norms, habits, and expectation (Willock et al., 1999). Chapters 3 and 4 show that institutional uncertainty occurs as a result of lateral leaders not conforming to rules on water discharge as scheduled within the Bontanga scheme. Farmers adapt by undertaking farming activities when water is discharged onto their farmlands. Hence, as supported by Kristensen and Jakobsen (2011), the 'irrational' farmer could be guided by rules and how they transform rather than by the consequence of alternative decision-making choices. In Chapter 4, we see that flexible rules on land rental and tenure within the Bontanga scheme present difficulties for non-indigenous rice farmers in their bid to secure land for farming. The informal approach to land rental arrangements presents uncertainty about negotiation outcomes. Thus, although the presence of an irrigation facility in the district could be described as a robust intervention by government, the variability in rules and uncertainty in outcomes of these rules exacerbate farmer woes, to which they have to adapt through decision-making.

Chapter 4 shows that determining farmer information needs could begin with understanding what uncertainties exist, the logics of decision-making, and how these play a role in adaptive decision-making. Arguably, drawing on adaptive decision-making by ascertaining uncertainties and logics of decision-making is a better way of interpreting information needs. However, most information service providers pay little attention to understanding decision-making contexts in farming systems that they serve. When they aim to deduce information needs, the new generation of climate information systems must be sensitive to substantive and institutional uncertainty evident in farming systems and probe adaptive decisions taken by farmers.

> ***Insight:*** *Farmers' adaptive decision-making is as much about dealing with uncertainty about rules as it as about dealing with uncertainty about environmental conditions in rice farming systems.*

7.4 Reflections on the conceptualisation of adaptive decision-making

From adaptive management to adaptive decision-making, it is evident that, even in an abundance of knowledge, uncertainty about future conditions remains a gap that must be filled in relation to natural resource (Lal et al., 2002). Increasingly, the aforementioned analogy has resulted in renderings on the concept of adaptive decision-making in scholarly works on bounded rationality and a discounting of classical rationalist thinking (Payne, Bettman, & Johnson, 1997). Rational decision theory, borrowing from Neumann and Morgenstern's (1947) expected utility theory, assumes that decision makers attempt to maximise their expected utility and hence make choices that offer the highest utility weighted by the probability of acquiring that option. That human behaviour is predictable has been (re)-framed as biased by context, experience, and the variation in options available for decision-making (Camerer, Loewenstein, & Rabin, 2004; Kacelnik, 2006), hence the argument that rationality is bounded and imperfect given incomplete information about alternatives, uncertainty, rules, and codes of conduct, limiting the ability of decision-makers to estimate the best course of action (March, 1978; Nilsson & Dalkmann, 2001; Simon, 1972).

The neo-institutionalist approach conceived by James G. March and Johan P. Olsen, where two logics (the logic of appropriateness and the logic of consequentiality) are contrasted, brought a new perspective and contribution to behavioural decision-making (Goldmann, 2005). They present a logic of action by which human behaviour can be interpreted. An action is said to follow the logic of consequentiality when 'it is driven by subjective assessment of outcomes of alternative courses of action', and the logic of appropriateness 'when it is shaped by rules relevant to the current situation' (Schulz, 2014). Both logics characterise the difference between deliberate and habitual action and have also been interpreted in the theories of bounded rationality (Schulz, 2014). However, the theories of bounded rationality in classical rational thinking assume the logic of consequences. A number of criticisms have been raised against what March and Olsen attempt to portray, including what Schulz (2014) points to as the persistence and shifts in logics: the reality that an action sometimes shifts between both logics along the path.

The studies in Chapters 3 and 4 contribute to the adaptive decision-making literature by discussing the transformational power of information in rice farming systems, with much reference to the neo-institutionalist logics of consequentiality and appropriateness. Scholarly research on adaptive decision-making in food systems has gained traction with significant empirical references (Beckford, 2002; Fosu-Mensah et al., 2012; Gbetibouo, 2009) but few attempts at conceptualisation. In Chapters 3 and 4, the dissertation makes a significant contribution to the conceptualisation of adaptive decision-making, given an observable intersect between the two logics of decision-making (March, 2011; March & Olsen, 2004) and the objects of uncertainty (Dewulf & Biesbroek, 2018; Koppenjan & Klijn, 2004) faced by rice farmers in Kumbungu District. This provides a deepened understanding of how information systems might not be impactful in instances where information communicated is devoid of a recognition of the objects of uncertainty with which farmers are faced. Thus, the relationship between uncertainties and logics of decision-making helps in interpreting adaptive decisions. In Chapter 4, I (re)-conceptualise adaptive decision-making by defining the concept as *a process of choosing non-standard decision options underpinned by the logic of consequentiality taking into account substantive uncertainty when assessing consequences, or, in line with the logic of appropriateness, taking into account institutional uncertainty when assessing appropriateness*. Willock et al. (1999) and Ohlmer et al. (1998) whilst discussing farmer decision-making paid little attention to socio-economic and psychological variables; this reinforces the need for re-framing to encompass psychological factors and to interpret farmer decision-making as a process rather than an event.

Consequently, adaptive decision-making is empirically contextual in food systems but can be universally conceptualised. However, I do agree that, given the interaction between rice farmers and other actors at farm/community level and how strategic choices occur, an expansion of the conceptualisation of adaptive decision-making to include strategic uncertainty (uncertainty about the actions of other actors) (Dewulf & Biesbroek, 2018) could provide more insight into adaptive decision-making. For example, within irrigation farming systems, strategic decisions at management level consequent to change in government policy and programmes could present farmers with the challenge of having to deal with the uncertainty associated with such choices.

> ***Insight:*** *Institutional uncertainty and the logic of appropriateness are apparent in adaptive decision-making just as substantive uncertainty and the logic of consequentiality also are.*

7.5 Climate information systems, information needs and actionable knowledge creation (RQ 3, Chapters 5 and 6)

7.5.1 Creating actionable knowledge through information systems

A key element of second generation information systems is the emphasis on actionable knowledge creation in social and ecological systems (Lourenco et al., 2016; Reinecke, 2015; C. Vaughan & Dessai, 2014). In food systems, dealing with uncertainties and water availability challenges through climate forecast information provision requires climate information systems to pursue an agenda of making information applicable in a given context. This involves ensuring that information provided meets the needs of end-users, with the potential of translating it into actionable knowledge for use in decision-making. In Chapter 5 of this dissertation, I explored how existing information systems enable actionable knowledge creation in rice farming systems in Kumbungu District. It emerged that information systems, be they digital or non-digital, support actionable knowledge creation in rice farming systems (Jayaraman et al., 2015; Ospina & Heeks, 2012). However, applying Cash et al.'s (2003) factors of salience, credibility, and legitimacy shows differences in how these information systems support actionable knowledge creation. Furthermore, Furman et al. (2011) reiterate that salience, credibility, and legitimacy are socially constructed, shaped by users' identity and beliefs and the value that users associate with a given piece of information. As shown in the chapter, to address the question of actionability in climate information systems, insight is required into the specific seasonal and weather information that is relevant for farmers and into how uncertainty and timing influence uptake for decision-making. Hence, in the study in Chapter 6, visually facilitated scenario workshops were used to explore how uncertainty and seasonal and weather lead times inform farmer decision-making.

The analysis in Chapter 5 revealed that farmer-to-farmer systems most enable the creation of actionable knowledge. As discovered by Feder et al. (2004) for pest management training in Indonesia, farmer-to-farmer systems diffuse information extensively. Such systems most enable the creation of salient knowledge thanks to their focus on local contexts in aligning information and making it usable. In this dissertation, the focus on the application of information at farm level enabled the raising of relevant questions such as: How is this information relevant to us as rice farmers in the area? What are the implications of the information received about farm activities given the time factor? Equally, in the effort to produce credible knowledge, farmer-to-farmer systems induced the legitimising of knowledge through open participation and sharing. Hence, every rice farmer could participate in informal meetings held in open spaces where farmer concerns were discussed. Also, farmer-to-farmer systems advanced the credibility of outcomes of deliberations by drawing on both indigenous and scientific information (see also Kniveton et al., 2015; Victoria, 2008).

In Chapter 5, it is shown that community radio systems (Jost et al., 2016; Tall, 2010) strongly support cross-fertilisation of knowledge by engaging experienced farmers in knowledge brokerage where both scientific and indigenous knowledge are considered during studio discussions. Simli Radio uses local languages in discussions and has periodic phone-in sessions, and these promote local listenership, participation, and the creation of salient knowledge.

Mobile-based-only platforms have also gained traction in enabling actionable knowledge creation in food systems (Evans et al., 2017; Asenso-Okyere & Mekonnen, 2012). The analysis in Chapter 5 reveals that a major shortcoming of existing mobile-based platforms is that the limited attention to, and recognition of, indigenous knowledge has a significant impact on the credibility of knowledge produced. Despite the success in breaking physical barriers to communication by using mobile technology, the focus on national and regional levels and only scientific forecasts limits the salience of emerging knowledge. Here, we see an emphasis on credibility rather than legitimacy and salience.

Chapter 5 points to questions on how the independent operation of each of these systems puts the farmer in a quandary in making sense out of what is communicated as information and largely what emerges as actionable knowledge. Although propositions are not offered on how a systems integration could be pursued in the form of joint architecture, opportunities for synergy and collaborative delivery of information aided by all systems are discussed.

Chapter 6 highlights the components of meteorological information that are relevant for farmer decision-making, with substantial insight into what climate information systems could do differently to enhance uptake under 'normal' conditions. The chapter contributes significantly to elucidating the risks that farmers are willing to take based on the information they receive. Regarding probabilities, the study shows that forecasts indicating a higher probability of rainfall occurring are not always favourable for farmers, with the possibility of farmers changing dates for carrying out intended activities such as land preparation, weed control, and fertiliser application because of their sensitivity to water conditions. Thus, climate information systems available in Kumbungu District must integrate these dynamics to better interpret what information eventually becomes actionable. In further establishing what lead times are best for communicating seasonal forecasts, it is evident in Chapter 6 that a 1-month lead time informs farmer decision-making better relative to a 2- or 3-month lead time. Thus, irrespective of farming type practiced, farmers are emphatic that a 3-month lead time is of no significance. Regarding weather forecasts, it emerged that a 1-week lead time is preferred over a 3-day or a 1-day lead time for in-season decision-making. However, providing forecasts within these lead times is technically challenging.

Thus, in Chapters 5 and 6, the dissertation provides critical input on farmers' information needs and their implications for actionable knowledge creation. For example, information provided can be scientifically valid or credible but not used if provided at an unfavourable lead time. Also, higher probability does not necessarily translate into action at farm level when farmers are convinced that undertaking a particular activity could be counterproductive in their particular circumstances.

> ***Insight:*** *Knowledge is most actionable when its credibility is based on scientific and indigenous knowledge through a participatory process of legitimisation that results in knowledge that is locally salient.*

7.5.2 Reflections on conceptualisation of actionable knowledge

Actionable knowledge is broadly represented in scholarship in management and organisation studies on how to bridge the gap between theory and practice (Antonacopoulou, 2007; Cassell, Denyer, & Tranfield, 2006; David & Hatchuel, 2007; Hatchuel, 2005). However, recent studies on how science and technology can improve the attainment of sustainability indices have drawn on the concept in connecting knowledge to action, with a predominant contribution by Cash et al. (2003) in science and policy studies, and other scholarship purporting to understand the transformational power of information in environmental management (Cross & Sproull, 2004; Evans et al., 2017; Ginige, 2016; Horan & Wells, 2005; McCampbell et al., 2018). The term, actionable knowledge, comprises two key words – knowledge and action – and has been defined differently in science and technology studies in an attempt to elucidate what information systems or knowledge systems have been and could be (Córdoba-Pachón & Paucar-Caceres, 2019; Evans et al., 2017).

Evans et al. (2017, p. 72) define actionable knowledge as 'knowledge that can be acted upon and applied to solve a real-world problem'. Geertsema et al. (2016) define actionable knowledge as knowledge that supports stakeholder decision-making and consequent actions. Carlile (2002) contends that actionable knowledge is produced with an underlying layer of expectation to transform conditions towards an expected end. Thus, the aforementioned authors relate actionable knowledge to that which commands uptake and is justified to the degree to which it informs decision-making. However, Hassard and Kelemen (2002, p. 333) remind us that the study of the production of knowledge should also consider the consumption of knowledge as this 'fuels the creation of new knowledge while new knowledge acquires its status as "knowledge" only when selected for consumption by important players'. Thus, they argue that the study of knowledge (and what could thus be actionable) should address questions not only on its production but also on its consumption, indirectly affirming the need to define the bridge between production and consumption in the form of actionable knowledge.

Bringing this into the discussion on climate change and agriculture, some scholarly works discuss actionable knowledge with an emphasis on scientific knowledge but not on indigenous knowledge systems (Kirchhoff et al., 2013), which equally influence the degree to which climate information is transformed into actionable knowledge. Hence, a re-conceptualisation of actionable knowledge in light of emerging concerns on climate change and the use of climate information towards creating relevant knowledge makes the inclusion of indigenous knowledge systems essential. In Chapter 3, I define actionable knowledge as *indigenous and scientific knowledge that is locally relevant, trustworthy, and produced in a fair, transparent way*. To this effect, knowledge production results from a fusion of both knowledge types, with reference to scientific and indigenous information. I point to the need not to limit the definition of actionable knowledge to scientists but also to include users of information systems, with an emphasis on co-creation through a process of continuous interaction and re-definition enabled by information systems (Bentley, Van Mele, & Acheampong, 2010; Nyantakyi-Frimpong, 2013). Actionable knowledge must encompass integrated scientific and indigenous salient and credible knowledge, produced through a legitimised process of fairness and inclusiveness. Essentially, not detaching knowledge production from consumption acknowledges the importance of collaborative framing of information needs, data requirements, and information towards creating actionable knowledge. Actionable knowledge, when implemented, has the tendency to generate new information, which feeds back into information systems and better validates new data with empirical evidence. As evident in Chapter 3, farmer-to-farmer systems most enabled the creation of actionable knowledge compared to community radio, mobile-based-only platforms, or commercial radio as a result of openness in engagement, empirical references, and justifications for new knowledge, given implementation in decision-making at farm level and the cycle of reflecting on the validity and salience of both scientific and indigenous knowledge. Hence, information systems, be they technologically driven or otherwise, must aim not only to bridge geographical and communication barriers, but also to improve actionable knowledge creation.

> ***Insight:*** *Actionable knowledge is an indicator of the potential of information to influence decision-making in food systems.*

7.6 Limitations

7.6.1 Methodology

The study contributes to scholarly research on how information systems could transform productivity in rice farming systems. However, a number of limitations can be highlighted.

Firstly, using an interdisciplinary approach necessitated the alignment of the work of PhD candidates addressing either the technical or the social aspects of the case study. This called for continuous brainstorming and engagement outside the immediate research questions throughout the period of the study. PhD candidates are expected to also collaborate in addressing research questions. For example, addressing RQs 1 and 3 involved periodic consultations between the two PhD candidates on this case and supervision teams. Although the approach provided multiple perspectives to answer research questions, the process was time consuming in juggling between technical and social lenses.

Secondly, the fact that this research was part of the bigger EVOCA programme placed it in a frame of multiple concepts, and hence the PhD candidates had to reflect on other concepts not directly related to their research questions. For most of these concepts, they stayed on the fringes, without rendering an in-depth scientific inquiry into them. For example, the EVOCA programme revolved around the concepts of citizen science, responsible innovation, connective/collective action, EVOs, and decision-making. However, this dissertation did not encompass an in-depth inquiry into the subjects of citizen science and connective/collective action. Thus, although the programme allowed for studies into other concepts (citizen science, social learning, collective action, connective action), the approach is a long iterative learning process transcending the duration of the PhD study.

Thirdly, the EVOCA programme sought an action research design to address the research questions. It is, however, worth noting that moving between the Netherlands and Ghana, given the sandwich arrangement of PhD programmes, limited the chances of addressing research questions through action research related to seasonality.

7.6.2 Testing a functional EVO

The study, whilst adding to how existing information systems contribute to knowledge creation and decision-making, points to a new course of action in relation to the design and framework of climate information systems. However, testing a new second generation climate information system would have provided justification, insights, and learning relevant for literature on climate information systems. Although this was not attainable over the four-year period of the PhD study, an experiment in the study context or another context must be pursued. With an emphasis on user-centred designs in the current discourse on climate information systems, studies such as this must aim to leverage outcomes not only for scientific purposes, but also for societal change in local contexts.

7.6.3 Generalisation of study outcomes

This study, using an exploratory approach, offers case-specific insights into information systems and the transformation of food systems through knowledge creation to support decision-making. The framing of actionable knowledge, for example, is dependent on indigenous, context-sensitive knowledge and its application. Furthermore, the existence of institutional uncertainty and substantive change means that the outcomes of this study might not hold scientifically true in other contexts with different environmental and institutional conditions. Nevertheless, the study's findings hold true and are applicable in the Ghanaian context and provide pointers for

Sahelian regions where farmers are faced with water scarcity conditions impacting their productivity at farm level.

7.7 Future research outlook

Adapting to climate variability and change in food systems is a complex subject with numerous unanswered questions. Although this dissertation addressed a number of these and the theoretical and empirical expositions have provided insights, it also raises further questions that must be investigated to improve the impact of information systems.

In Chapter 2, the study launches into design thinking on second generation climate information systems. Although the ex-ante approach used here points to a possible framework that could enable the integration of indigenous knowledge and scientific information, improved participation, and usability of information, further studies are needed to take the debate further. Specifically, the relationship between concepts such as responsible innovation, citizen science, and virtual observatories for environmental monitoring in food systems must be investigated and not limited to climate information provision and use.

In Chapters 3 and 4, I present findings related to framing adaptive decision-making with reference to rules and institutional uncertainty (see also Edwards-Jones, 2006). Hence, frameworks on adaptive decision-making must consider appropriate rules of behaviour and not just environmental change. A next step will be to develop an index for measuring adaptive decision-making based on rules of behaviour. Exploring this in other contexts will provide much insight into how best to index rules and their transformation and institutional uncertainty as a component of farmer adaptive decision-making to better contribute to scientific debates.

In Chapter 5, I discuss how existing information systems in Northern Ghana are enabling actionable knowledge creation for decision-making. The dissertation also presents reflections on opportunities for collaboration between information systems to improve actionable knowledge creation. I also point to the need for further research on how a systems integration approach could be explored to improve information synthesis and actionable knowledge creation in rice farming systems (see also Murakami et al., 2007). As shown in the chapter, information systems operated with limited collaboration, resulting in instances of duplication of functionality and services. Although a competitive atmosphere is healthy, there is need for further research on how the network of systems could improve the timely and accurate delivery of information. This, however, is a question not only about the architecture of systems, but also about how the process can enhance the use of information in farming systems in Ghana. Given the agenda to enhance interoperability within existing telecommunication networks in Ghana, it is worth exploring how such infrastructure could improve productivity in the agriculture sector through ICT (see also Alemna & Sam, 2006; Al-Hassan, Egyir, & Abakah, 2013).

Further research is also needed on conceptualising and operationalising actionable knowledge in farming systems to create value from information, as highlighted in Chapter 5. In this dissertation, much reference is made to Cash et al. (2003) on actionable knowledge, with a (re)-framing of salience, credibility, and legitimacy in Chapter 5 to encompass both indigenous and scientific knowledge. Nevertheless, an integration of both knowledge systems must be a conscious process undertaken by information service providers. Currently, most information systems operating in Ghana rely on scientific information to provide seasonal and weather forecasts to farmers. Integrating both knowledge systems enhances the actionability of knowledge (see also Kalanda-Joshua et al., 2011). However, the potential for integrating both indigenous and scientific data is still a grey area that needs further studies in Ghana.

7.8 Societal relevance

In this dissertation, I make a substantial contribution to addressing the climate–water–food security challenge in the study area and in Ghana in general, detailing how information systems could be used to transform productivity in farming systems. A summary of the societal relevance of the study for the district, country, and global community is presented below.

The study findings point to areas of synergy that information service providers can explore to maximise their economic benefits and also enhance outcomes and impacts of their operations in Bontanga and its environs. Service providers are implored to recognise farmers and other end-users as key players in defining their operations in the area. Mobilising farmer support for data gathering can be strongly pursued at limited cost and compensation to investigate the potential of indigenous forecasts and knowledge. The PhD candidate engaged farmers directly in establishing what indigenous knowledge could be relevant for use in information systems. From the study, farmers' quest for solutions to uncertainties and water management challenges resulted in their willingness to support any intervention that reduced the uncertainties that they encounter given the consequences of climate variability for their farm practices.

Also, this dissertation offers greater insight for food governance at district level. With government's effort to support rice production to meet country level demand in Ghana, insights from this study provide a lead for the District Agriculture Development Unit (DADU) on how best to strategically support rice farmers within its district to increase output and productivity at farm level. It also points to the institutions with which the unit should collaborate for mutual investment and benefit. As emphasised, one key challenge that farmers have to manage is how to make sense of information accessed from different sources. Here, by engaging all actors in healthy dialogues through workshops and seminars, DADU can take up the agenda of how best to enhance collaborations.

The dissertation brings into perspective the impact of climate change in the rice sector in Ghana, providing empirical evidence of the transformative power of technology and information relevant for policy decision-making. With the current drive towards a digital economy and the adoption of a technological strategy to transform the agriculture sector, this dissertation adds to the discussion by highlighting how addressing design, knowledge, and decision-making dynamics can accelerate change at local level. The dissertation emphasises how a participatory process can be pursued to enhance local participation in, and acceptance of, digital innovations when framed through conscious policymaking and implementation. Policy strategies emphasising partnership between private and public institutions operating within the space of agriculture information provision is clearly encouraged given the outcomes of this study. In effect, rural economies, which serve as the food basket for the country, could be transformed, with impacts on livelihoods and externalities in the form of strong local economies negating poverty indices and levels of youth unemployment.

Also, within the agenda of agriculture transformation using technology, the dissertation elaborates on relevant areas for consideration and points to the need to create the opportunity for indigenous innovations. It also highlights the need to think of the digital space as an ecosystem entailing not only technical but also socio-cultural and institutional infrastructure, without which technological solutions could fail. Thus, entrepreneurs must be encouraged to work in teams comprising different disciplines, enabling reference to both a social and a technical lens to develop ideas into scalable products. With the private sector estimated to set the pace as the engine of growth, government policy and programmes should create an enabling environment for agri-tech companies, especially indigenous enterprises, to maximise growth and eliminate instances where entrepreneurs have to fold because of financial incapacities fuelled by high taxes. As much as possible, government must partner with private enterprises for shared learning, experimenting, and upscaling innovations in the agriculture sector in Ghana. For independent investors aiming to enter the digital space in Ghana, the dissertation provides relevant resources that could inform their decision-making and investment strategy. The need for tailor-made solutions responsive to the Ghanaian context is promoted, given the results of this study. This insight points to the need for strategic collaboration with existing information service providers to improve information uptake and the achievement of investment priorities.

The dissertation makes reference to a very significant but untapped resource: citizens (in this case smallholder farmers) living in rural areas who could be engaged directly in the drive to transform the agriculture sector in Ghana. As elaborated in Chapter 3, indigenous knowledge acquired through the years in the field could strongly inform data collated by institutions such as Ghana Meteorological Agency, the Ministry of Food and Agriculture, and associated agencies and departments to improve the accuracy of weather and seasonal forecasts. The dissertation acknowledges the role of citizen science for which the ministries, departments, and agencies have yet to set as an agenda. Although perceived as an expensive process, establishing a clear framework anchored on civic principles of volunteerism and responsible citizenry could help reduce cost components of data collation over the long term to transform agriculture and food security indices in the country.

With a global drive towards smart agriculture and digitalisation of the food chain, the findings from this research render insights, especially in the context of the global South. From the dissertation's outcomes, I establish how knowledge creation is critical to ensuring the bridge between agriculture information provision and use. I also point to how socio-cultural dynamics frame the digital ecosystem, suggesting the need for global efforts to emphasise a bottom-up approach towards transforming the agriculture landscape using technology. Equally, solutions at a global scale must be monitored to establish the trickle-down effect of their adoption and use amongst farmers in communities. Hence, a comprehensive global approach to ensuring food sufficiency through technology involves identifying and setting up the right governance framework anchored on the principles of participation and balance of power, whilst addressing barriers that inhibit progress in this regard.

7.9 Conclusions

In this dissertation, I set out to achieve two main objectives: to provide an understanding of the information–knowledge–decision-making relationship aided by information systems in dealing with the climate–water–food challenge in rice farming systems in Ghana; and to discuss how climate information systems can improve farmers' ability to adapt to changes in water availability conditions in rice farming systems by supporting the generation of actionable knowledge to support farmer decision-making.

I have contributed to the climate information systems framework, drawing on the concept of EVOs. I have also contributed thoughts on responsible innovation in highlighting the need for information systems to prioritise participation, reflexivity, responsiveness, and anticipation whilst exploring the possible engagement of citizens as scientists in the design and operationalisation of information systems. I have pointed to strengths and limitations of existing information systems in the study area and what could be done differently to enhance productivity in the rice farming systems studied. A key suggestion highlighted is for new information systems to explore how they can be embedded in existing information setups with greater inclusivity and community ownership as driving factors. I have also illuminated how indigenous data could be combined with scientific data to improve the accuracy of weather and seasonal forecasts, which is a grey area.

Secondly, I have provided the insight necessary for deepening the understanding of the concepts of actionable knowledge and adaptive decision-making, which are key elements of second generation EVOs. In the transition towards improving the usability of data and information, attention to the aforementioned concepts will enhance the transforming power of information in information systems. For this, I have (re)-conceptualised the aforementioned concepts in the context of rice farming systems and proposed a new framework for climate information systems to make them more useful.

I have pointed to the need for further discussions on leveraging existing information and technology ecosystems in rural areas in developing countries (using Ghana as a case), as a first step to improving knowledge in the sector. Indirectly, I have added to the discourse on the potential of rural areas, which are currently central to food production and food security in the country. I have added to how digital technologies can transform the agriculture sector in developing economies and hence propose replication of this study in other jurisdictions with similar characteristics.

I have highlighted decision complexities by establishing the interlinkage between uncertainty and decision logics, thereby furthering scientific research on understanding farmer decision-making in food systems. In an era where data and information are the new oil, it must be acknowledged that obtaining the right data to support decision-making and transformation in farming systems will require establishing decision dynamics in appropriating data. Clearly, uncertainty can only be managed and not eliminated, and hence the degree to which data and information can bring certainty about the uncertainty faced by farmers promises assurance on return on investment and the collective goal of improving food security, especially in deprived regions of the world. Adaptation is a data question, an information question as well as a decision-making question, also bringing to bear the need to establish the right governance structures to support information service delivery.

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Supplementary material

Supplementary Material-A

Belonging to Chapter 3: Governance arrangements and adaptive decision-making in rice farming systems in northern Ghana

Appendix 3a: Interview guide for farmers

A. Background of Farmer

1. Can you please tell me a bit about yourself (age, education, occupation, etc.)?
2. If you have a family, can you tell me about them (family size, age of children, gender, etc)?

B. Information on the community and social relations

3. How long have you lived in this village?
4. How do you think the natural environment in this community has changed over the years?
5. What is your opinion on community relations in this village?
6. Do you think community leaders as chiefs and assembly members are still influential in affairs in the community? Explain.

C. Land Tenure and Farming in the Village

7. Who owns lands in this village and how can one access land for farming?
8. What are the common arrangements between landowners and farmers who do not own lands?
9. What major farm crops are cultivated in this village and why?
10. Are there sometimes disputes about land? How are these settled?

D. Governance and decision-making at the farm level

11. As a rice farmer, what are the decisions you have to take every farming season?
12. Considering the decisions mentioned, how does one decision affect the other?
13. Which decisions do you take alone and why?

14. Which decisions do you usually take with the rest of the family and why?
15. What are the roles played by you and other family members on the farm?
16. How do you define or determine the roles each family member plays?

E. Governance and decision-making at the group level

17. In the case where you do, who do you interact with during decision-making in the farming season who are not family members?
18. What decisions do you make with them and why?
19. What decisions don't you make with them and why?

F. Water management decisions in rice production

20. What factors do you think affect water availability during the rainy season as well as the dry season?
21. What decisions do you take on water use during the rainy season in irrigated/non-irrigated rice production to ensure continuous water availability?
22. What decisions do you take on water use during the dry season in irrigated/non-irrigated rice production due to ensure continuous water availability?
23. What actions do you take as a farmer engaged in irrigated/non-irrigated rice farming as part of water management on your farm?
24. How effective were the actions you took in the just ended production season on water use?
25. What do you think accounted for the failure or success of the decisions you took last season on water use?

G. Adaptive decision-making on water management in rice production

26. What are some of the decisions you had to quickly change last season when you noticed failure of rains and other water sources you use?

27. How easily are you able to change decisions on water use due to change in circumstances such as the rains, temperature and the weather during rice production?
28. Tell me about a certain event and how did you react (get stories) (rice culture) (decision practices in rice farming) (dealing with water availability can follow later)
29. Do you know the extent to which other farmers have been flexible with adaptive decision-making?
30. Did the new ad-hoc decisions you took contribute positively to your rice production process?

H. Improving adaptive-making in water management

31. How do you think farmers can improve the decisions made in water management in rice production?
32. How do you think collective decision-making could better improve adaptive decision-making than individual decisions or otherwise?
33. Any other comments?

Thank you for your time

Appendix 3b: Guide for focus group discussion

1. What water challenges do you as farmers face within the season?
2. Which periods of the main farming season are most sensitive to water issues?
3. What other resources affect your ability to meet water needs?
4. What technical, environmental and social challenges do you think affect water availability and supply?
5. What written or unwritten rules guide water use both within and outside the scheme?
6. How do you collectively manage the challenge of water scarcity under rainfed or irrigated farming systems?
7. How do you think farmers can improve the decisions made concerning water management in rice production?
8. How do you think collective decision-making could better improve adaptive decision-making than individual decisions or otherwise?
9. Any other comments?

Thank you for your time

Appendix 3c: Interview guide for water managers

I. Background of water manager

1. Can you please tell me a bit about yourself (age, education, occupation, etc.)?
2. If you have a family, can you tell me about them (family size, age of children, gender, etc)?

J. Water manager role play

3. How long have you been working as a water manager on this irrigation scheme?
4. Have you managed similar irrigation schemes before?
5. How do you think this scheme differs from the previous one you managed?
6. Do you think there are lessons from your past experience that have shaped your present performance? If so how?
7. How relevant do you think the role of the water manager is in the overall management of the scheme?

K. Stakeholder Analysis and decision-making

8. What frameworks define role play and decision-making in the irrigation scheme?
9. Which stakeholders do you take decisions with in the irrigation scheme?
10. At what stages of the farming process do you engage with these stakeholders?
11. What decisions do you take alone as a water manager and why?
12. What decisions do you take with other stakeholders and why?
13. If you had your own way, which stakeholders will you like to work closely with and why?
14. If you had your own way, which stakeholders will you not like to work closely with and why?

L. Water management in the Scheme

15. What are the water related challenges you face in the scheme?
16. What are the decisions you have to take due to challenges in water availability for the effective operation of the scheme in both rainy and dry seasons?
17. Which of these decisions do you take together with farmers?
18. What decisions are you easily able to change especially in the dry season?
19. What decisions are you not able to change in the dry season?
20. How are the decisions you are able to change affect water availability?
21. How do the decisions you are unable to change affect water availability?

M. POCC of scheme

1. What do you think are the success factors of the scheme?
2. What do you think are the challenges faced by the scheme?
3. What opportunities do you think exist which can be tapped to improve the performance of the scheme?
4. What external factors do you think have influenced negatively or served as threats to the survival of the scheme?

Thank you for your time

Supplementary Material-B

Belonging to Chapter 5: Information systems and actionable knowledge creation in rice farming systems in northern Ghana

Appendix 5a: semi-structured interview guide for rice farmers

Name of Farmer: Name of Community:

Tel: Production system: a) Irrigated only b) Rain-fed c) Both

Ownership: Mobile Phone ☐ TV ☐ Radio ☐

A. Information systems and Information provision

Period	Information system	Service provider	Language	Type of information
Pre-season	Mobile Phone			
	Community radio			
	Commercial radio			
	Farmer-to-farmer			
	Other……………			
Land preparation	Mobile Phone			
	Community radio			
	Commercial radio			
	Farmer-to-farmer			
	Other……………			
Planting	Mobile Phone			
	Community radio			
	Commercial radio			
	Farmer-to-farmer			
	Other……………			
Weed control	Mobile Phone			
	Community radio			
	Commercial radio			
	Farmer-to-farmer			
	Other……………			

Fertilizer application	Mobile Phone			
	Community radio			
	Commercial radio			
	Farmer-to-farmer			
	Other……………			
Harvesting	Mobile Phone			
	Community radio			
	Commercial radio			
	Farmer-to-farmer			
	Other……………			
Marketing	Mobile Phone			
	Community radio			
	Commercial radio			
	Farmer-to-farmer			
	Other……………			

Information interpretation/sense making/Actionable knowledge

1. Is the information you have received above at this time of the season timely and relevant for you?
2. What challenges do you face in interpreting the information?
3. What cost did you incur in accessing this information?
4. Do you usually have to confer with other farmers what to do with information received? How do you do that? Does it make any difference?
5. Would you describe first-hand information received through the mediums you cited as one that you can act on immediately? Please explain your response?
6. Is the information you are receiving this season providing you with new knowledge that you never knew? Please explain.
7. What cycle of consultation do you do at the household level before you act on information you receive?
8. What cycle of consultation do you do at the scheme/community level before you act on information you receive?
9. Do you think a non-educated farmer could have trouble interpreting the same information you received? Please explain.

Thank you for your time

Appendix 5b: Interview guide for focus group discussion with farmers (Knowledge co-creation)

1. What is the objective for organising rice farmer meetings?
2. How often do you organise such meetings and why?
3. How does new farm related information received contribute to your agenda at meetings?
4. Do you have any arrangements with institutions for information relevant to your farm activities? If yes, how did you establish this?
5. What do you think limits your ability to use information you receive as rice farmers?
6. What cycle of consultations are held with other actors outside the group after your meetings?
7. Are there usually agreed decisions on actions to be taken during your meetings at the group level?
8. What are some of the decisions that were made in your previous meeting?
9. Do you hold emergency meeting to take new decisions when you receive new information? Why?
10. How have new decisions based on new information improved your adaptation to uncertain farming conditions like the weather and rain fall patterns?
11. Do you think you can take more strategic decisions at your meetings if you had representatives from institutions providing you with information participating?
12. Is there any documentation or record keeping at your meetings? Can you share such with me?

Thank you for your time

Appendix 5c: Interview with Information System Operators (ESOKO,

1. What is the mission of this organization?
2. How are you involved in information provision in the agricultural sector?
3. Could you share with me the stages you go through to gather relevant information that you share with farmers?
4. Which actors/institutions do you consult in the information gathering process?
5. Which institutions do you currently partner in delivering agricultural related information to farmers and other beneficiaries in the agricultural sector?
6. How are farmers involved in the information gathering process?
7. What challenges pertain in gathering relevant and timely data for dissemination to farmers?
8. How is the leadership of your beneficiary communities in and around Bontanga involved in your operations?
9. How do you overcome language barriers involved in communication and transfer of relevant knowledge or information to your end users?
10. How it technology helping you achieve the aim of disseminating information?
11. How is mobile telephony playing a role in your operations with end users?
12. How do you meet the cost requirements for information gathering and dissemination to end users?
13. How is technology playing a role in your engagement with farmers?
14. What do you think are the prospects of an IT platform that brings you and other stakeholders together for information and knowledge development management for agriculture?
15. How do you measure the impact of information disseminated amongst end-users like farmers?

Appendix 5d: Interview with Community Leaders

1. What is your role in this community?
2. How are you directly involved in information dissemination?
3. How are you involved in decision-making in this community?
4. If you engage directly with farmers, how and when do you do that?
5. What challenges do you face in disseminating information to farmers and water managers?
6. How is the channel for information dissemination embedded in your culture and way of doing things?
7. How do you contribute to providing farmers with relevant information for their activities?
8. How do culture and community norms affect information dissemination arrangements?

Appendix 5e: Checklist for Observations at Farmer Meetings

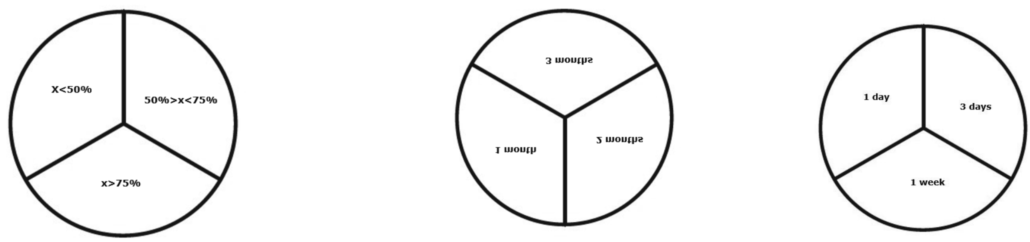
(Knowledge co-creation/learning)

- ✓ Which actors participate in local meetings to discuss concerns of rice farmers?
- ✓ How is new information received?
- ✓ How is new information interpreted and by whom?
- ✓ How are women involved in discussions?
- ✓ How does power influence role play and contributions during discussions?
- ✓ Is literacy a key indicator of participation and contributions?
- ✓ Are farmers enthused to be part of meetings?
- ✓ Does participation by some farmers appear to be mere formality?

Supplementary Material-D

Belonging to Chapter 6: Forecast probability, lead time and farmer decision-making in rice farming systems in northern Ghana

Appendix 6a: Farming stages as shown on the cardboard



Wheel 1: Forecast probabilities   Wheel 2: Forecast Lead Time (Seasonal) Wheel 3: Forecast Lead Time (Weather)

Decision Card Board

Appendix 6b: Seasonal forecast lead time and farmer decision-making.

	One Month Lead Time		**Two Months Lead Time**		**Three Months Lead Time**	
	Freq.	**%**	**Freq.**	**%**	**Freq.**	**%**
Will Act	31	86.1	22	61.1	8	22.2
Will not Act	5	13.9	14	38.9	28	77.8

Appendix 6c: Weather lead time and farmer decision-making

Farming stages	**Decision Choice**	***One Day Lead Time***		***Three Day Lead Time***		***One Week Lead Time***	
		Freq.	***%***	***Freq.***	***%***	***Freq.***	***%***
Land Preparation	Will clear the land using manual labour	4	11.1	9	*25*	26	72.3
	Will clear land using a tractor	32	88.9	27	75	10	*27.8*
Planting	Will broadcast seeds	32	88.9	25	69.5	23	63.9
	Will nurse and transplant seedlings	4	11.1	6	16.7	7	19.4
	Will plant using dibbling method	-	-	5	13.9	6	16.7
1st Fertilizer Application	Will apply fertilizer by broadcasting before the rain	1	2.8	6	16.6	17	47.2
	Will apply fertilizer by placement after the rains	35	97.2	30	83.4	19	52.8
Weed Control	Will apply weedicide after the rains	3	8.3	1	2.8	36	100
	Will apply weedicide before the rains	33	91.7	35	97.2	-	-
2nd Fertilizer Application	Will apply fertilizer by broadcasting before the rain	4	11.1	16	44.4	13	36.1
	Will apply fertilizer by placement after the rains	32	88.9	20	55.6	2	60.4
Weedicide Control	Will apply weedicide by spraying after the rain	29	80.5	5	13.9	2	5.6
	Will apply weedicide by spraying before the rain	7	19.2	31	86.1	34	94.4
Harvesting	Will harvest with a sickle	27	25	27	25	13	36.1
	Will harvest with a combine harvester	9	75	9	75	23	63.9

Appendix 6d: Guide for VFSMP

VISUALLY FACILITATED WORKSHOP

ESTABLISHING HOW CLIMATE INFORMATION INFORMS FARMER ADAPTIVE DECISION-MAKING

PROTOCOL DESIGNED FOR WORKSHOP

[8]

[8] Image Source: http://www.bm3school.com/2016/12/group-decision-making.html

Preface

This document has been designed as a guide to conducting a so-called visually facilitated workshop to further understand how rice farmers' deal with complex water related issues within their various farming systems. The approach and content was developed by the Water Case team of the EVOCA PhD Programme led by PhD students on the case. The project is a four year study (2016-2019) with the aim of developing a functional hydro-climatic Environmental Virtual Observatory for water management in rice farming systems in Northern Ghana.

Preliminary phases of the PhD work were aimed at identifying and understanding key issues such as governance arrangements, information access and use, climate forecast from both indigenous and scientific sources as well as decision-making dynamics. This workshop is expected to be a build-up on critical issues identified and purposely focus on how different aspects of climate information will influence farmer decision-making. It is anticipated that the outcomes of the study will significantly shape the final design of a hydro-climatic Environmental Virtual Observatory following the highly participatory process of citizen science, collective decision-making and a bottom-up innovation process.

Step 1: Setting Up

The workshop must be organised in a congenial atmosphere. Facilitators must ensure a number of conditions are in place for a successful workshop.

A. Venue

The venue for the workshop is important. Although the settings of most rural areas makes it difficult to access well-furnished state of the art facilities, most rural communities have facilities such as community centres, durbar grounds, local administrative assembly meeting halls and classrooms. Facility chosen as venue for the workshop must be:

i. Spacious and comfortable for participants
ii. Enclosed to avoid distraction from movement within the immediate environment outside the venue
iii. Comfortable seats for participants
iv. Well ventilated with enough lighting

B. Logistics/Materials

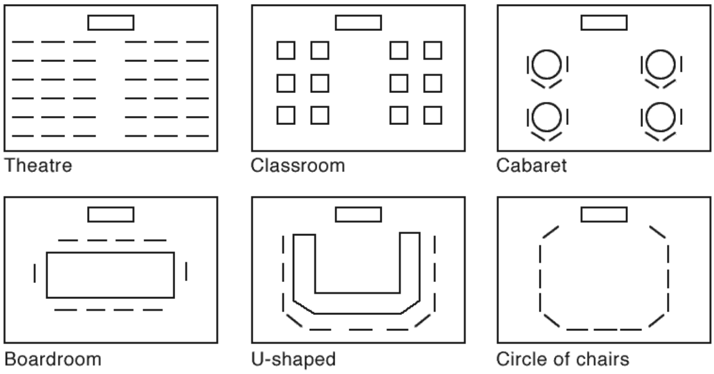
A number of logistics must be made available as inputs for the workshop. These include:

- Flip charts, Markers, Spiral wheel (3), Solution tape, Tables, Cameras, Recorder, Name tags (optional), Registration desk

-The setting must have a table and chairs for the facilitators. Farmers do not necessarily need a table but just comfortable chairs to sit on. At some points, the arrangement could be restructured to allow for sub-groups to work independently. Tables and chairs could be arranged in the theatre style, u-shaped style or in a circle where convenient. Other arrangements could be considered depending on how convenient. Facilitators must set up the spiral wheels, flip charts, registration desk and all basic requirements. This is to avoid any distractions during the main workshop.

Key participating groups are: Facilitators, rapporteurs and farmers.

Workshop set-up style



Source: http://rikkiarundel.com/getting-the-room-set-up-right/

Step 2: Communicate workshop agenda

Do not read: *Ask all present to take their seats. As much as possible, try to get participants to mix up irrespective of gender.*

Read: You are all welcome to today's workshop. My name is…………and I will be the facilitator for the opening session of the workshop. I will like the facilitators and every other participant to introduce him or herself after which I will take over to communicate to you the objective of the workshop. In your introduction, kindly state your full name, your community and what type of rice farming you practice.

Do not read*: Allow a few minutes for introduction*

Read: Thank you for the wonderful introduction. Today we are gathered here further continue what we as researchers and you as farmers have been working together on…ie. Helping manage water needs in rice farming by providing a climate information system which can be used by you the farmers with our support. So far, we have all understood the challenges you face as farmers in your decision-making under the different farming systems. We have come to know that water is fundamental to your activities as rice farmers and hence for today's workshop, our objective is to further engage with you on how best to use your indigenous knowledge and scientific information to improve information precision and reduce uncertainties that you face from weather variability and its consequences on rainfall and water availability. This workshop promises to be an exciting session and we hope that we all enjoy it. As your facilitator I am in charge of this workshop and hence I will direct how proceedings will go. By way of protocol, if anyone wants to make a point the person may kindly raise his hand and draw my attention. Also, when anyone one is on the floor making a suggestion or input, please do not interrupt by making any further contribution until you are asked to do so.

Do not read: *You can demonstrate the last bit of observing decorum by using mentioning names of participants… "For example, if Mr………raises his hand to make a point, as a facilitator I have the right to give him or her the opportunity to speak. When I do, I do not expect Mr…….to also be talking on the side in the audience."*

Read: At this point, I will want to ask if anyone has a question or is not clear as to why we are gathered here.

Do not read: *Give a minute for any question…..*

Step 3: Update on PhD field research so far

Do not read: *Facilitators should present to the audience the phases of the project and what has been done s far. This could be a PowerPoint presentation or an oral presentation.*

Read: At this point, I will invite my other colleague facilitator to give you an overview of how far we have come with this project based on our engagement with you for the past three years. We encourage everyone to be attentive and focused so you can ask any questions you have after the presentation. This part is very important before we get to the main activity for the workshop. Shall we welcome him with a hand of applause…

Do not read: *Presentation should not exceed 10 minutes and must address the following questions…*

i. What is the nature of the climate-water-information-decision-making challenge?
ii. Why is addressing this important to researchers and farmers?
iii. How will this workshop contribute to managing the challenge?

***Read**:* Thank you Mr…….for your presentation. At this point, I will open the floor for any questions. Please raise your hand if you have any question. Remember to mention your name first and then you follow it up with your question. Please try as much as possible to be clear in your thoughts and be specific with the question. In case you have any point or question, do not condemn another for his or her question, you can just make your point or ask your question without condemning another.

***Do not read**: Please check from time to time with rapporteur if he or she has been able to capture questions, suggestions and responses or explanations.*

--------10 mins break----

Step 4: Introduce Visual based Exercise

***Read**:* This stage of the workshop is very participatory and hence we will encourage everyone to get on board. So far, the workshop has been interesting with an excellent presentation and questions. At this stage, we as facilitators will engage you in an interactive exercise. The objective of the exercise is to create scenarios which you as farmers are faced with regarding information and what decisions you will take in response to them. Once again, we encourage you all to participate in this exercise.

***Do not read**: facilitator should move to the items to be used in the exercise and explain what each one is to be used for and how that ultimately contributes to the entire exercise.*

***Do not read**: Explain the certainty and uptake wheel (Wheel 1)*

Read: This wheel has many colours with each colour representing something important for the exercise. The wheel will be used to determine the level of certainty associated with information we will be giving you. Since the certainty level will not be fixed, one of you will be made to spin the wheel so determine the level of certainty at each point in time. As written and shown by the colours, Green represents a certainty of 75% or above. Yellow represents a certainty of between 50% and 75% and Red represents a certainty less than 50%. Thus green means the likelihood of the event happening is 75% or above, whereas yellow means the likelihood of the event happening is between 75% and 50%. Red means the likelihood of the event happening is 50% or less.

Do not read: *Explain wheel 2 and 3*

Read: Now both of these wheels represent the lead times we want to experiment. We intend to establish how seasonal and weather forecast lead times inform your choice and decisions under the different circumstances and conditions.

Do not read: *now explain the season cardboard*

***Read**:* The season board as shown details out the standard major decisions that you as rice farmers make in the season. We have added pictures that further explain the decisions. The season cardboard is very important for this stage of the workshop. Our discussions will go through the seven stages of key decisions as shown on the cardboard.

Do not read: *Lastly is the computer which has the list of adaptive decisions farmers are likely to take at each stage of the farming season. Farmers should not be told this to avoid the thought of being graded based on what adaptive decisions they end up making.*

Read: *Does anyone have any questions at this stage please?*

Step 5: Visual based Mapping

***Read**:* We now need you to be more attentive. We will have to get one volunteer to spin wheel 1 which shows the level of certainty and wheel 2 and 3 also showing seasonal and weather forecast lead times respectively. After spinning each wheel, we will engage with you individually on what decisions you will take and also what decision you will also take as a group for the various decision phases of the farming season. We will allow you sometime when it is time to take the collective decisions so you discuss amongst yourselves what decisions to take and why. On the individual decisions however, we do not expect you to discuss anything but rather we will engage you one-on-one to know what decisions you will take and why. After this then we discuss what decisions you will make as a group based on this. The exercise will be done over seven decision stages. The collective decisions you make at each stage will be written out clearly on a flip chart and discussed at the end of each decision stage.

Do not read: *The facilitators can demonstrate this by going through the phases of the exercise practically for farmers to see. The literate farmers could be made to provide interpretation support at each phase of the exercise.*

Do not read: *Facilitate the process over the seven rounds with discussions on what adaptive decisions farmers make and why. Observe how group decisions are made. Do a few hijack the decision-making process? Do women farmers contribute? Are the experienced farmers dominating the discussion?*

Step 6: Discussion and conclusion

Read: Thank you for participating in the exercise. We appreciate your efforts and involvement. At this point we all want to discuss a few things to better understand how and what informed your decisions as well as the way forward in designing a climate service to provide relevant information for your use. We have about 5 questions we will want you to answer.

I. What are your impressions about the methods we used in this exercise to ascertain how information informs your decision-making?

II. Do you think the approach gave you enough opportunity and time to brainstorm or better express yourself on what you wanted to communicate at each stage? If Yes or No, explain your answer.

Do not read: *Now facilitators can ask the following questions if observed.*

III. Hijack of decision-making process: It appears a few persons (mention names if possible) dominated the decision-making process within the group. Could there be a reason for that?

IV. Gendered decision-making: Were women given enough opportunity to contribute to the decisions by the group? If not why?

Closing….

Read: We will like to take this opportunity to thank each and every one of you for availing yourself to participate in this important workshop. It serves an important input to designing the information system which we all are aiming at. There is refreshment after we close. Please do avail yourselves for any subsequent workshop what we will be organising in the coming weeks or months. We have some refreshment for you. Thank you once again.

Summary

The adverse impacts of climate variability and change on water availability in food systems continuously present farmers with the challenge of adapting their practice and decisions to better manage uncertainties with which they are faced. This includes the pursuit of information on seasonal and weather conditions so as to establish what choices to make to ensure that water needs are met. In rice farming systems in Ghana, farmers practising rainfed and irrigated farming rely on forecasts made available through information systems operated by institutions in the public and the private sector. Although the provision of meteorological forecast information is expected to reduce risks faced by farmers, the reverse has been the case in some contexts because of not only the limited availability of information at scale, but also the challenge of interpretation as well as the trustworthiness of information. With numerous information systems operational in the sector, farmers are also burdened with having to make sense of each system, how it operates, and what can be collectively deduced from all these systems towards informed decision-making. A fundamental argument for the failure of information systems to make the needed impact is the limited engagement of users and the lack of a highly participatory process of monitoring environmental change, defining what should constitute information, and how best to make sense of information for decision-making. In addition, institutional change and the existence of documented and undocumented rules framing social interaction and practices in farming systems present uncertainties in some context with direct and indirect impacts on land tenure, access to water for irrigation, and labour dynamics.

Recent literature has suggested that a new crop of information systems must be developed, emphasising inclusive design, collaborative data gathering, and the cross-fertilisation of knowledge to enhance uptake in decision-making. In this context, environmental virtual observatories, which refer to a suite of information gathering, processing, and dissemination technologies (infrastructure, tools, and software) supported by World Wide Web that can enable cross-fertilisation of different sources of knowledge on shared virtual platforms, have been cited. To investigate this, this dissertation addresses three key questions to understand how climate information systems could serve as enablers of greater productivity in rice farming systems:

RQ 1. What empirical and theoretical dispositions could guide the design and operationalisation of climate information systems in rice farming systems in Northern Ghana? (Chapter 2)

RQ 2. How do governance arrangements inform farmer adaptive decision-making given uncertainty and information needs? (Chapters 3 and 4)

RQ 3. How do existing information systems enable actionable knowledge creation and what information could better improve decision-making in rice farming systems? (Chapters 5 and 6)

The dissertation adopts an interdisciplinary approach and a case study research design. It also employs qualitative research methods such as focus group discussions, interviews, workshops, and observations. The dissertation comprises five academic articles, with article 1 focused on RQ 1; articles 2 and 3 addressing RQ 2; and articles 4 and 5 answering RQ 3.

Using an ex-ante approach, Chapter 2 establishes a possible climate information systems framework that responds to the tenets and principles of responsible innovation. This comprises an assessment of existing information systems, their challenges, and what could be done differently. The chapter also entails insight into governance arrangements and a proposition of structural elements for climate information systems. The assessment revealed that emphasis on a participatory design as a principle will enhance ownership and involvement of local actors, more especially farmers, thereby increasing the chances of acceptance and usage of the climate information system. In meeting the principle of anticipation, the proposed climate information system addresses farmer concerns about future variability in seasonal and weather conditions. An emphasis on reflexivity through a collaborative process between natural and social scientists and a recognition of uncertainties about what information is to be provided will ensure the delivery of realistic output devoid of failed expectations. Included, among other

things, is a discussion on how citizen science could potentially enhance the potential of drawing on both indigenous and scientific information within the system.

Chapter 3 investigates further governance arrangements in irrigated and rainfed rice farming systems and how these significantly inform adaptive decision-making. The empirical study shows that formal and informal arrangements guide the design of irrigation plans, land distribution and ownership, and labour arrangements. For example, the degree to which labour arrangements could be made informed the adaptive decisions that farmers take during land preparation. Secondly, although formalised regulations defined how supplementary irrigation should be done, weak supervision of the operations of lateral leaders resulted in unfair water distribution, pushing farmers to adjust their practices and decisions in this regard.

Chapter 4 discusses in-depth the substantive and institutional uncertainties faced by farmers in choice-making and the underlying logics of decision-making evident in farmer adaptive decision-making. The chapter reveals that both the logic of consequentiality and the logic of appropriateness evidently characterised farmer adaptive decision-making. The chapter highlights information needs of rice farmers, given adaptive decisions. It also identifies the adaptive decisions that are common amongst rice farmers.

Chapter 5 examines information systems and how they contribute to actionable knowledge creation in rice farming systems. It emerged that farmer-to-farmer systems strongly support the creation of actionable information thanks to a highly participatory process of information and knowledge sharing through dialogue and considerable reference to both scientific and indigenous information in a face-to-face setting. The chapter also adds to the literature on the conceptualisation of actionable knowledge with reference to both scientific and indigenous knowledge. It is emphatic on the fact that, although mobile technology as a tool has helped to overcome physical barriers to communication and to ease the interaction between information service providers and users, its transformative power is yet to be felt in the broader framing of actionable knowledge.

Chapter 6 draws on outcomes of Chapter 2, adding to discussions on farmers' information needs, given how these inform farmer decision-making. Using a visually facilitated scenario modelling workshop, the study in this chapter explored how probabilities and lead times (seasonal and weather) shaped farmer decision-making. Findings from the empirical study suggest that a seasonal forecast provided at a 1-month lead time rather than earlier is significant for farmers to act through decision-making. Also, farmers preferred weather information provided at a 1-week lead time rather than at a 3-day or 1-day lead time, as this affords farmers enough room to take and implement decisions in the form of practice.

This dissertation thus strongly contributes to scientific explorations of how information systems can better help farmers deal with uncertainties in the form of climate variability and change, for which there is no end in sight. It also contributes to conceptualisations of the concepts of uncertainty, actionable knowledge, and adaptive decision-making. More broadly, it adds to current discourse on suitable frameworks for climate information systems.

About the author

Andy Bonaventure Nyamekye was born on the 7th of January, 1987 in Koforidua in Ghana. He hails from Shama in the western region of Ghana. He is a product of Mfantsipim School where he had his Senior High School education. He also completed his Bachelor and Master degrees at the Kwame Nkrumah University of Science and Technology in Ghana. Andy belongs to a family of five and is second among his siblings.

Following his master education, he worked at the Kumasi Institute of Technology, Energy and Environment (KITE) as a projects officer and was integral in numerous successful projects undertaken between the period of 2013 to 2015. As an interdisciplinary researcher, he specialises in the domains of energy, food, water and climate change and has authored a number of scientific articles in this regard. He also has rich experience in project management given his experience at KITE and other assignments he has been involved in.

List of publications

Nyamekye, A. B., Dewulf, A., Van Slobbe, E., Termeer, K., & Amedi, A. (under-review). Hydro-meteorological Information, Uncertainty and Adaptive Decision-making in Rice Farming Systems in Northern Ghana. Journal of climate services.

Nyamekye, A. B., Nyadzi, E., Werners, S. E., Biesbroek, R. G., Dewulf, A., Van Slobbe, E., ... & Ludwig, F. (under review). Forecast probability, lead time and farmer decision-making in rice farming systems in northern Ghana. Journal of climate risk management.

Frimpong Boamah, E, **Nyamekye, A.B,** (Under review). Understanding smallholder farmers' adaptation to water challenges in sub-Saharan Africa. Journal of environmental policy and governance.

Nyamekye, A. B., Dewulf, A., Van Slobbe, E., & Termeer, K. (2019). Information systems and actionable knowledge creation in rice-farming systems in northern Ghana. African Geographical Review, 1-18. Available at: https://doi.org/10.1080/19376812.2019.1659153

Nyamekye, A. B., Dewulf, A., Van Slobbe, E., Termeer, K., & Pinto, C. (2018). Governance arrangements and adaptive decision-making in rice farming systems in Northern Ghana. NJAS-Wageningen Journal of Life Sciences, 86, 39-50. Available at: https://doi.org/10.1016/j.njas.2018.07.001

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Completed training and supervision plan

Andy Bonaventure Nyamekye
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Name of the learning activity	Department/Institute	Year	ECTS *
A) Project related competences			
Climate change adaptation in the water sector, ESS 34806	Earth System Science, Wageningen University	2016	6
Designing innovative governance arrangements, PAP 30306	Public Administration and Policy, Wageningen University	2016	6
EVOCA PhD modules	Communication, Philosophy and Technology	2016	6
Extreme citizen science	EVOCA Management Committee	2016	1.3
Effective strategies for academic writing	EVOCA Management Committee	2018	1.3
Introduction to interpretive Research Design	WASS	2016	3.0
PhD research proposal	Public Administration and Policy/ Earth System Science	2016	6
Companion Modelling	PERC	2016	1.5
1st EVOCA Workshop	EVOCA Management Committee	2016	1
2nd EVOCA Workshop	EVOCA Management Committee	2017	1
3rd EVOCA Workshop	EVOCA Management Committee	2018	1
4th EVOCA Workshop	EVOCA Management Committee	2019	1
B) General research related competences			
WASS introduction course	WASS	2016	1
NVIVO-based qualitative data coding and management training for social scientist	WASS	2019	1
'Information systems and actionable knowledge creation in farming systems'	5th Adaptation Futures Conference, Cape Town	2018	1
Digital ethnography	EVOCA	2018	0.5

Convener Wageningen PhD Symposium	WUR PhD Council	2018	0.3
C) Career related competences/personal development			
Posters and Pitching	Wageningen in'to Languages	2018	1
Total			**39.9**

This research was financed by the Wageningen Interdisciplinary Research Fund (INREF) as part of the EVOCA programme titled “Responsible life-science innovations for development in the digital age: EVOCA”.

The EVOCA programme also covered the cost of design and printing of this thesis.

Cover design: Luc Dinnissen (studio ds)
Book cover image: Ignitia, Tropical Weather Forecasting
Layout: Andy Bonaventure Nyamekye
Printed by: proefschriftmaken (htttp://www.proefschriftmaken.nl/en)