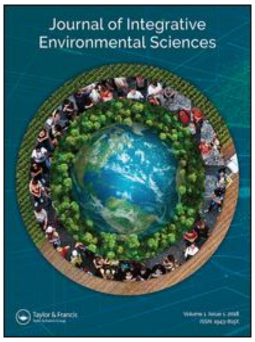

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Adaptive decision-making under conditions of uncertainty: the case of farming in the Volta delta, Ghana

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ABSTRACT

Farming in Ghana's Volta delta is increasingly affected by variability in rainfall conditions and changes in land-use patterns. Under such socio-ecological conditions, little is known about farmers' decision-making in response to uncertainties in uncertain rainfall conditions. To fill this gap and add to the literature on adaptive decision-making, we addressed the central question: what are the existing patterns of farming decision-making under uncertain rainfall conditions, and which decision-making strategies are adaptive? We developed an adaptive decision-making framework to investigate the behavior of farmers under variable rainfall conditions in Ghana's Volta delta in the Ada East District. We conducted 5 interviews with agricultural extension agents, 44 in-depth interviews and 4 focus group discussion with farmers. Subsequently, we interviewed a sub-selection of 32 farmers. Findings of the study shows that farmers carry out different decision-making patterns in response to the variable rainfall conditions. We distinguished six strategies: three based on flexibility and three based on robustness. Flexible adaptive decision-making strategies are switching dates for sowing seeds through wait-and-see or delay strategy, muddling through the farming season with the application of various options and alternative irrigation strategies. Robust adaptive decision-making strategies are portfolio strategy of transplanting seedlings in batches, selection of robust (hardy) crops, and intercropping or diversification. Based on how farmers select strategies in response to uncertainty in rainfall conditions, we argue that some decision-making strategies are more adaptive than others. Findings of this study are relevant for the design and implementation of climate related agricultural projects.

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Introduction

Deltas are dynamic regions which play relevant roles towards sustainable livelihoods and development. Most delta regions in Asia and Africa host growing populations as they are the interface between the land and the sea (Woodroffe et al. 2006). As a result, several livelihoods including, fishing, salt production, tourism, trade, farming and other economic

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activities thrive in deltas (Robert 2017). Despite the socio-ecological and economic benefits derived from deltas, they are gradually vulnerable to several environmental stressors such as coastal erosion, sediment deposition, seawater intrusion and changing climatic conditions (Addo 2015). These phenomena threatens food security, increases poverty and the sustainability of livelihoods such as farming.

In the Volta delta in southern Ghana, several socio-economic activities such as fishing, aquaculture, sand mining, fisheries, salt mining and tourism are carried out due to the dynamics of water (Addo et al. 2017). However, farming is one of the main economic activities with huge potential for livelihood and sustainable development in the area (GSS 2014). Yet, the sustainability of farming is being undermined as the Volta delta is undergoing socio-economic and physical transformation due to urbanization, expansion of townships and intensive cultivation of food crops (Roest 2018). Intensification of farming is driven by the need to supply agricultural produce to markets in the adjoining cities and towns (Boubacar et al. 2005; Awadzi et al. 2008). Despite intensification, farming in the delta is carried out under uncertain water availability conditions (Amisigo et al. 2015). Water conditions in the delta are characterized by:

- Increasing incidences of drought, high temperatures, flooding and variable rainfall conditions (Ofori-Sarpong and Annor 2001; Owusu et al. 2008; Teye and Owusu 2015).
- Coastal erosion and salt intrusion from sea level rise (Mul et al. 2015; Roest 2018).
- Increasing degradation of natural resources especially freshwater resources, due to an expanding population (Roest 2018).
- Environmental changes due to the construction of hydroelectricity and irrigation facilities upstream (Andreini et al. 2000; Mul et al. 2015; Anthony et al. 2016) and
- Low groundwater table inland and the presence of few water infrastructures such as dams, canals, wells and piped water supplies.

However, the incidence of variability in rainfall is the main water challenge which affects smallholder farming. Rainfall conditions in the delta are marked by increased variability, declining rainfall total, and a shift in rainfall regime towards long dry spells, late onset of seasonal rainfall and early cessation of rainfall (Gbangou et al. 2019). Southern Ghana including the delta area has a bimodal rainy season, locally referred to as the main season (April–July) and the minor season (September–November). Early cessation of rainfall in the main rainy season has resulted in prolonged dry seasons with increased evaporation, while reduction in rainfall amount occurs in the minor season (Owusu et al. 2008). Additionally, the annual evaporation rate (1785 mm) exceeds the annual rainfall in the Volta delta region (Addo et al. 2017).

The incidence of spatial and temporal variability in rainfall in the Volta delta (van de Giesen et al. 2010), affects farmers' reliance on rainfall to cultivate crops. The application of irrigation for farming is limited to the embankment of the distributaries of the Volta river because hydrological construction on the upstream and mid-stream section of the river has affected the flow and course of the river channel (Anthony et al. 2016). Access to groundwater for irrigation farming is also limited to the coastal sandstrip (Gyampoh et al. 2011; Yidana and Chegbeleh 2013). Therefore, farmers who are engaged in irrigation and/or rainfed farming are all affected by variability in rainfall conditions. Farmers are constantly left in a dilemma and their decision-making is often marked with several questions – "when is it likely to rain; when do I plough; when do I sow my seeds; will the seeds succeed under the current rainfall condition; should I pump water into the farm, apply fertilizer and the agrochemicals or not, What about if I irrigate now or spray the farm with agrochemicals and then it rains afterwards?" The uncertainty in rainfall conditions, intensive farming situations and the context of dynamic environmental interactions in the Volta delta requires that decision-making for farming is adaptive to ensure sustainable food production throughout the farming seasons. Adaptive decision-making in farming is carried out on short-term and long-term basis in response to both weather and socio-economic and environmental context (Robert et al. 2016).

There is a growing body of literature on decision-making trying to understand how farmers respond to uncertain conditions in the farming context. Previous studies have analysed decision-making under rainfed and drought conditions (Risbey et al. 1999; Keshavarz and Karami 2014; Singh et al. 2016), adaptive capacity to climate change (Wiid and Ziervogel 2012; Hoang et al. 2014), adaptation strategies (Fosu-Mensah et al. 2012; Yaro 2013; Ndamani and Watanabe 2015) and adaptation in farmer decision-making process (Merot et al. 2008; Guillaume et al. 2016; Robert et al. 2016, 2018). Roesch-McNally et al. (2017) examined adaptive strategies in the context of decision-making and farmers' intention to increase their use of three production practices: no-till farming, cover crops and tile drainage across the US Corn Belt. Studies focussing on farm-level decision-making under uncertainty (see Fafchamps 1993; Yengoh et al. 2009) indicate that most farmers use bet-hedging strategies to minimize risks of production failure. Findings of a study carried out in Ghana and Cameroun also suggest that factors such as scale of production, long-term productions, success of technologies in the past and the adoption of technology by opinion leaders among other factors affect the decision-making strategies of farmers (Yengoh et al. 2009). In a similar study, Fafchamps (1993) used a stochastic control model to give account of farmers' behaviour under rainfed farming in the African semi-arid tropics, Burkina Faso. The study found that there is high demand for labour in the event of an early rainfall and this brings about the occurrence of manpower shortages. As a result, farmers incorporate the idea of flexibility in their farm productions as there is a strong relationship between labour and land productivity in various agro-climatic zones of West Africa. Despite the focus of the above-mentioned studies on decision-making in farming, there is a marked gap in the number of empirical studies which explicitly analyse farmers' adaptive decision-making under uncertain conditions.

Additionally, little conceptual coherence exists on how adaptive decision-making ought to be analysed. To fill the empirical and conceptual gap, we analyse how water-related decision-making in farming under uncertain rainfall conditions is adaptive or not, by focusing on the processes and strategies. The main question is: What are the existing patterns of farming decision-making under variable rainfall conditions and how adaptive are the decision-making strategies? To enable us answer the question, we developed a conceptual framework for adaptive decision-making by building on the existing literature on decision-making and we empirically studied farming in the Volta delta, in the Ada East District, Ghana. The Volta delta is the land below 5 m contour in the downstream section of the Volta River basin (Addo et al. 2017). It is made up of nine administrative districts; yet, we selected the Ada East District for the study because it lies at the interface between several waterbodies (Volta estuary, the Songor lagoon, wetlands) and the use of the land mainly for farming (GSS 2014). Despite the existence of waterbodies, access to water for farming in the Ada East District (the western section) of the Volta delta and river, is a challenge as compared to the Anloga-Keta sandpit (eastern section) of the delta which has shallow groundwater due to the geological formation in that area (Awadzi et al. 2008; Yidana and Chegbeleh 2013). In the subsequent sections of this paper, we reviewed relevant literature to conceptualize adaptive decision-making under uncertainty in socio-technical-environmental conditions. It is followed by sections on methodology, findings, discussions and conclusions, respectively.

Conceptualizing adaptive decision-making

In a general sense, decision-making is a process of selecting options to deal with a specific condition. Uncertainty lies at the centre of decision-making in complex conditions because it is difficult to assess the consequences of any given decision option when these are influenced by a range of uncertain socio-technical-environmental conditions. In real-life situations, uncertainty constitutes a major obstacle to effective decision-making (Lipshitz and Strauss 1997). Therefore, decision-making is not only about generating options but it also involves dealing with uncertainty.

In this study, we define uncertainty as the state whereby there is no unique and complete knowledge about the condition to be managed (Brugnach et al. 2008) due to unpredictability, incomplete knowledge or ambiguity (Dewulf and Biesbroek 2018). The role of information becomes relevant in uncertain condition as too little or too much information results in uncertainty (Brugnach et al. 2008). This implies that uncertainty is dynamic depending on the information that is available about the condition that needs to be dealt with.

When socio-technical-environmental conditions become increasingly complex and characterized by uncertainty, rational and linear approaches to decision-making have not been able to deal with uncertainty inherent in it (Philips 1997). Moreover, the application of "most-likely future" or "static optimal options" in decision-making under uncertainty have not produced effective outcomes (Hallegatte et al. 2012). A promising way of dealing with uncertainty in decision-making in complex socio-technical-environmental conditions is through adaptive decision-making. Adaptive decision-making builds on bounded rationality (March 1991) by considering uncertainty through incorporation of *flexibility* and *robustness* (Haasnoot et al. 2012, 2013; Dittrich et al. 2016; Kwakkel et al. 2016)

We define adaptive decision-making (ADM) as a pattern of decisions characterized by the application of decision options that are *flexible, robust* or both, in response to uncertain socio-technical-environmental conditions. The concepts *flexible* and *robust* are mostly used as a characteristic of deep uncertainty and long-term adaptation planning in infrastructure (see Lempert and Schlesinger 2000; Groves and Lempert 2007; Colombo and Byer 2012; Hallegatte et al. 2012). Additionally, the concepts are also often mentioned as components in adaptation to climate change planning in general and they are a subtype of adaptation planning theory. In the conceptualization of *flexible* and *robust* in our definition of ADM, we positioned the concepts on a general level as they have been applied in other fields regardless of the time horizon. For instance, the concepts have been applied in spatial planning (see Smit and Wandel 2006); adaptive management theory (see Williams and Brown 2014) and farm-level decision-making in the long and short term (Robert et al. 2016). In the subsequent paragraphs of this section, we explain the key concepts (*flexible* and *robust*) in the definition of ADM.

The first concept which is key in the definition of ADM is the application of *flexible* options. Under *flexible* ADM, options are selected in a way that they can be adjusted or reversed over time when additional information becomes available (Colombo and Byer 2012; Haasnoot et al. 2013). It is based on the notion that uncertainty is dynamic. Thus, additional information is analysed continually to aid in the selection of further options. This enables the strategy to be modified when there is a change in socio-technical-environmental conditions over time. This means that the initial decision does not result in a situation where new arrangements cannot be made (Colombo and Byer 2012). *Flexible* ADM also deals with uncertainty by providing room for learning about changes in socio-environmental-technical conditions over time (Pahl-wostl et al. 2007). Thus, when the initial option no longer meets the condition, additional options are generated in order to achieve a desired goal. Strategies used in applying *flexible* options include wait-and-see or delay in decision-making and introducing new or additional options when circumstances change (Colombo and Byer 2012; Yousefpour et al. 2017).

The second concept in the definition of ADM is the choice of *robust* options. It indicates the use of options that are effective in a wide range of socio-technical-environmental conditions (Lempert et al. 2006). *Robust* ADM helps to anticipate or mitigate the impacts of uncertainties in order to minimize regret (Kwakkel et al. 2016). The options are selected despite incomplete information about their consequences (Lempert et al. 2006; Yousefpour and Hanewinkel 2016) and aim for *robustness* rather than optimality (Lempert and Groves 2010). The selection of options under *robust* ADM can be achieved with different strategies. For instance, the use of a portfolio strategy enables multiple selections from a discrete set of options (Nalley et al. 2009), such that some options still work when others fail.

We propose that due to the uncertainties which characterize socio-technical-environmental conditions and the limited knowledge about options that are available to deal with, the application of *flexible* or *robust* decision options can be carried out on temporal basis, which could either be *proactive* (in anticipation of uncertain future changes) or *reactive* (in response to unexpected observed changes) *ADM* (Robert et al. 2016).

It is important to note that the application of *flexible* or *robust* options does not always lead to "successful" decision outcomes because many factors can influence the consequences of options in complex socio-technical-environmental conditions (Payne et al. 1993).

Methodology

Study area

The study was conducted throughout the farming seasons in the year 2017 in the Ada East District. The Ada East District lies in the southeast portion of the Greater Accra Region of Ghana. It is about 110 km drive from Accra (the national capital of Ghana) and Tema (the industrial city of Ghana) (Addo et al. 2017). It covers about 289 km^2 with a population of 71,671 based on the 2010 Population and Housing Census. The District shares common boundaries with the Central Tongu, South Tongu and the Ada West Districts and bounded to the south by the Gulf of Guinea (GSS 2014). The Ada East District is the main district which lies in the interface of natural, biophysical and socio-institutional, cultural and economic development (Figure 1). That is, the Ada East District has the Volta river estuary at Ada Foah. It also has commercial salt mining, agriculture, livestock rearing, agro-processing, fishery, shrimp and tilapia farming, mining of oysters, craftsmanship, trading, collection of non-timber forest products, the service sector and tourism as economic activities that are practiced in the area. The area experiences variability in rainfall condition in terms of too much, too little, too late or early rainfall and it is affecting farming (Gbangou et al. 2019). Since the district lies in the coastal savanna agroecological zone, it forms part of the areas which receives the least amount of rainfall in Ghana (Teye and Owusu 2015). It also has wetlands such as swamps and mangroves with 80% of cultivable land area (Figure 2). As such, the main economic activity practiced in the district is farming by 80% of households (GSS 2014). Farming is rainfed in the greater part of the district (Kasseh and Big Ada zones) except that pockets of irrigations are carried out on the bank of the Volta River and the coastal sandstrip. The district exhibits a combination of rural and urban characteristics because it has linkages with several urban communities such as Accra, Tema, Prampram, Dawhyenya, Sogakope, Aflao, Denu, Keta, Kpone, etc. (GSS 2014). Two periodic community markets held at Ada Foah and Ada Kasseh draw people from various places to trade in agricultural and other products. We selected the Ada District in the Volta delta for the study because farmers produce crops under different water conditions to meet demands from the urban areas. The conditions under which farmers produce crops provide us with a rich context to study decision-making in farming under

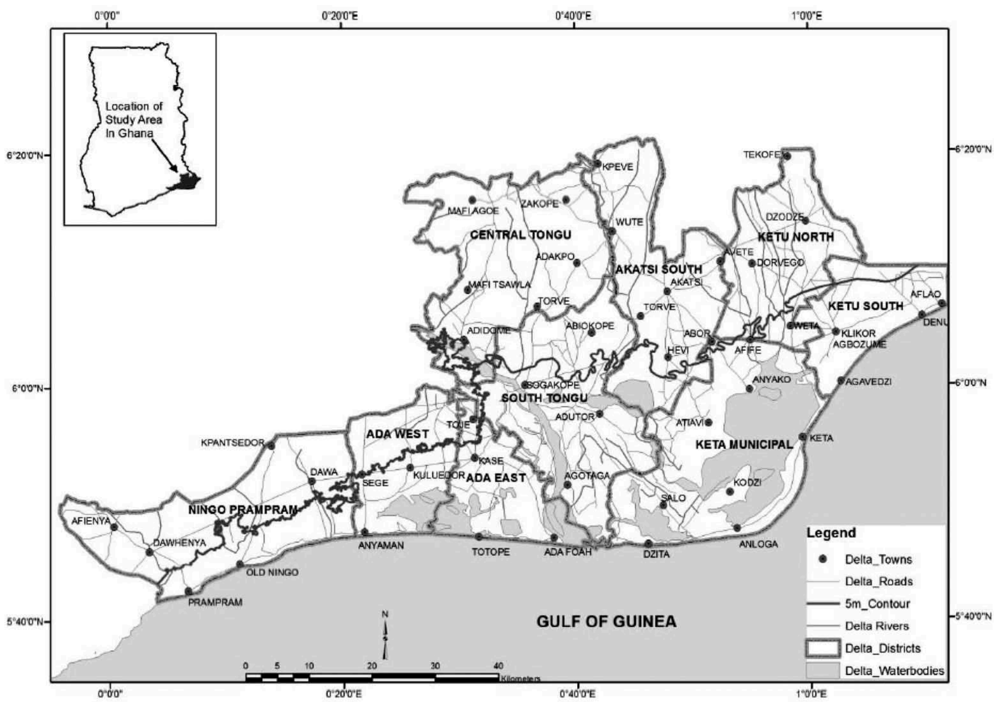

Figure 1. Map showing the Volta delta.
Source: Addo et al. 2017.

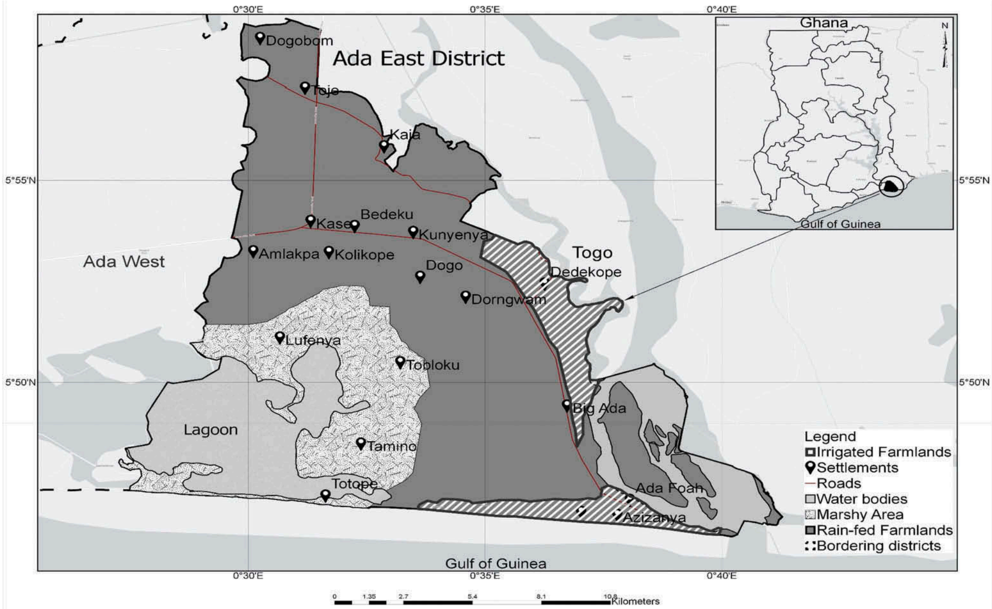

Figure 2. Map of Ghana showing the Ada East District.

uncertainty. In addition, the existing knowledge about farming communities and agricultural extension services by the lead author enabled us to carry out interviews and hold group discussions.

Research design

We used an exploratory in-depth case study research design to analyse how water-related decision-making in farming under uncertain rainfall conditions is adaptive or not, by focusing on the processes and strategies of farming in the Volta delta, specifically, the Ada East District. Based on the theoretical framework (Section 2) and empirical considerations (Section 3), we applied a novel research design to meet several analytical needs: (a) Preseason farming (refers to the period, January to March when crops are cultivated immediately before the start of the main rainfall season); (b) Main season farming (refers to the farming period which coincides with the main rainy season; that is, from April or May until July); (c) Minor season farming (usually spans the September to November during which minor rainfall events are recorded); and (d) Strategies of adaptive decision-making across the three farming seasons to analyse whether or not farmers decision-making is adaptive or not.

We used qualitative research methods, including, key informant interviews, in-depth interviews and focus group discussions to generate data for the study. We used the qualitative research approach because we sought for detailed information about rainfall condition, decision-making strategies and the application of the strategies under different rainfall conditions. At the onset of data collection, little information existed on how farmers carried out adaptive decision-making in response to variable rainfall conditions and how we can derive the information from farmers. Therefore, the application of the qualitative research approach enabled us to carry out data collection iteratively and also conducted the interviews, code and analyse the data in a flexible manner. We were able to revise the initial direction and framework of the research when the quality of information generated at the first and second stages of the study did not provide the required results. We included field observations and focus group discussions; thereafter, we were able to derive indicators of decision-making strategies and the number of raining days (see Table 1). Subsequently, we conducted a second round of interview with some farmers who were initially interviewed. During the data collection process, we were not limited to particular questions and we flexibly directed the structure of the research process until we were satisfied that the data generated has information which could answer the research question.

The lead author has experience in qualitative research as she had conducted extensive qualitative research on various agricultural topics and also participated in various qualitative research courses at different academic levels. She is also familiar with the geographic and socio-economic contexts of farming in the study area. Because data gathered through qualitative research approach is based on experiences, the rich background and experiences of the lead author enabled follow-ups on interesting answers with additional questions. This enhanced the overall database of information that was generated from the study area. The research design is presented in Figure 3 and operationalized in seven steps: Key informant interviews; Interview with farmers; Analysis of data generated from the first two stages; Construction of decision-making table step 1 and 2; Interviews with farmers using the decision-making table; Cluster decision-making table into patterns for three seasons and Identifying adaptive decision-making strategies. We provide details on the activities that were carried out in various steps of the research process below:

Step 1: key informant interviews

We started the study by eliciting information from agricultural extension agents who were key informants and were in charge of three agricultural zones in the Ada East District: Kasseh, Big Ada and Ada Foah. These zones were subdivided into 5 areas under the jurisdiction of 5 agricultural extension agents. We interviewed the agricultural extension agents to derive first-hand information about the decision-making strategy of farmers and various categories of farmers because they have knowledge on farming practices in diverse communities in the district. Agricultural extension agents were interviewed through face-to-face interactions, where they were asked to describe farming activities, farmers' decision-making patterns, cropping cycles, weather events and other relevant issues which affects farming in the district.

Step 2: interview with farmers

The methodological orientation underpinning the study is ethnography; as such, ethnographic interviews, in-depth-interviews, observation and focus group discussions (FGDs) were all used to generate information on daily, weekly, seasonal decision-making practices of farmers in response to rainfall conditions. Each agricultural extension agent had an average of 10 communities under their jurisdiction. They each selected 7–12 farmers from

Table 1. Decision-making table under water availability condition in 2017.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall condition	**Abnormal**	**Normal**	**Normal**	**Normal**	**Normal**	**Above normal**	**Below normal**	**Abnormal**	**Normal**	**Normal**	**Normal**	**Abnormal**
Rainy days	**3**	**0**	**1**	**7**	**14**	**15**	**10**	**5**	**6**	**8**	**5**	**3**
Amount of rainfall	**26 mm**	**-**	**10 mm**	**113 mm**	**201 Mm**	**80 mm**	**78.2 mm**	**14.2 mm**	**46.4 Mm**	**70.2 mm**	**40.8 mm**	**32.2 mm**
Options		**Selected Crop**				**Selected Crop**				**Selected Crop**		
Ploughing												
Land preparation												
Sowing												
Nursery												
Transplanting												
Water resource exploitation												
1st Fertilization (N.P.K)												
Thinning												
Weed control												
2nd Fertilization (Urea)												
Pest control												
Soil moisture conversation												
Water conservation												
3rd fertilizer (ammonia)												
Fruit booster												
Harvesting												

Source: Authors' construct based on field interviews, 2017.

Key:

1= selection of option under a specific rainfall condition in a month.

0= No decision-making.

= Preseason, = Major season, = Minor season, = abandoning of options.

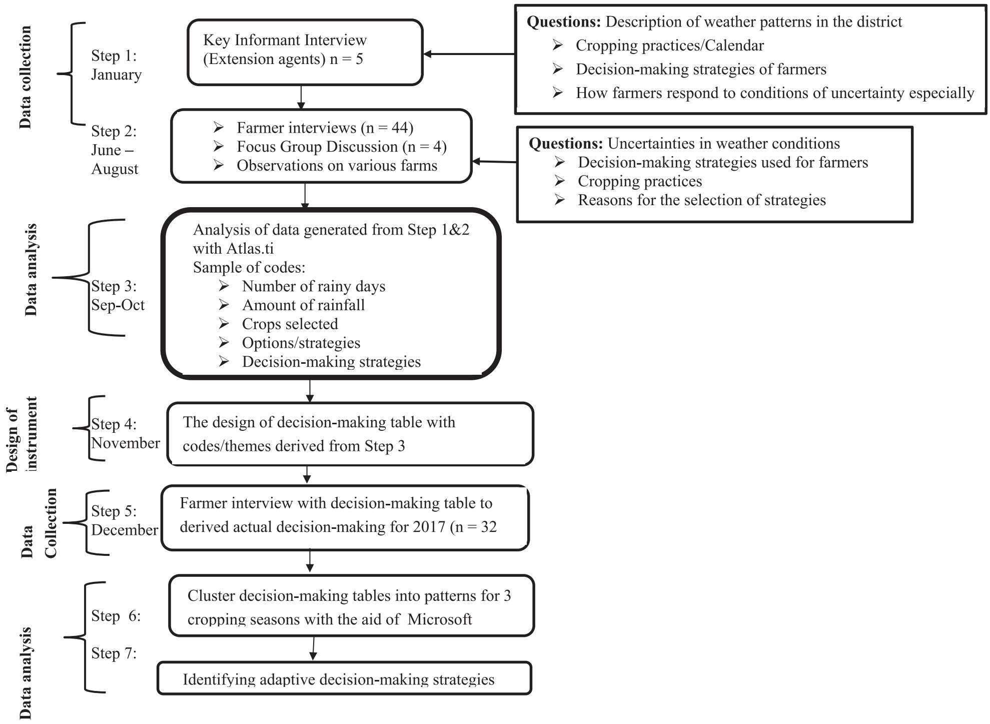

Figure 3. Summary of field methods used for data collection.
Source: Authors' construct based on field interviews, 2017.

communities in their respective operational areas for the interview. The number of farmers interviewed in each community varied depending on the availability of farmers as well as the homogeneity of the information that was provided. None of the farmers who were approached to participate in the study refused to grant interviews when the objective of the study was explained to them. There was no relationship established between the lead researcher and farmers before the fieldwork was conducted. Therefore, the connection to the communities was mainly set up by agricultural extension agents who identified various categories of farmers, based on the description of the objective of the research by the lead author. The criteria used for the selection of interviewees were guided by gender, age, years of experience, the source of water for farming, level of education and their role in the community (e.g. peasant farmers, lead farmers, opinion leaders or members of a farmer-based organization) (see Table A1). The total number of farmers selected for the study comprised 44 farmers (33 men and 11 women). Few women participated in the study due to the fact that they were mostly engaged in the processing and trading of farm produce. The face-to-face interviews were conducted through home visits in order to interact with farmers at their convenient time.

The lead researcher was sometimes assisted by agricultural extension agents or opinion leaders in the communities who introduced her to farmers and also arranged the appropriate time suitable for interviews to be conducted. Since the lead researcher is a female, the presence of agricultural extension agents who were males also allowed access to male-dominated farming "spaces" and that facilitated conversations during the interviews.

The interview guide was designed based on an extensive literature review guided by the objective and theory of the study. The interview guide was first piloted with 5 farmers and an agricultural extension agent in a community. Afterwards, alterations were made before the actual interviews were conducted. In the face-to-face interviews, farmers were asked to describe uncertainties in weather conditions, cropping practices and decision-making strategies at the initial, middle and end stages of the cropping seasons. The strategies and the reasons why they were selected were also discussed by farmers. Some farmers emphasized that if a prior response was not successful under a rainfall condition, they considered an appropriate alternative strategy.

In order to derive data on the rainfall conditions in the study area, we took rainfall records from farmers who have created rainfall charts (rainfall days) in different communities. We took farmers' rainfall records because they experience variability in rainfall in-between communities, whereas the official weather data from the meteorological station at Ada Foah are generalized for all the communities in the district. Therefore, farmers' records were slightly different from the data generated from the meteorological station. Since we sought to understudy farmers' decision-making in response to the availability of rainfall, we took farmers rainfall records. Even so, we compared farmers' rainfall records with the official meteorological records and there were few difference in terms of rainy days in some communities. Therefore, we took the decision to use farmers rainfall records since their decision-making coincided with their records (rainfall). Armah et al. (2015) indicated that when meteorological records are incomplete or unavailable, information on local perceptions of climatic changes can be used to complement scientific weather evidences because local or place-based evidence of weather changes gained through experiential learning can also be effective than simply studying analytical weather data. Hence, although temperature, evaporation, windy and humidity conditions were experienced by farmers, they kept records on only rainfall days. There were slight difference of 2 or 3 rainfall days among some communities for the months, June–July as some farmers did not consider drizzles or showers as rainfall, while others did. For the months January–May and September–November, the rainfall days were equal with the exception that the dates of the actual occurrence differed. Farmers' records about the amount of rainfall were classified as "normal rainfall", "above normal rainfall", "below normal rainfall" and "abnormal rainfall" conditions because they do not have rain gauges. Farmers regarded below or above normal rainfall conditions as "bad" weather whereas an "abnormal rainfall" condition refers to the occurrence of a rainfall condition in a perceived dry month. We used the number of rainy days as a guide in discussing "good", "bad" and "abnormal" weather conditions during the cropping season and the decision-making associated with it.

The interview process was repeated with farmers in different communities until no new decision-making strategy and information were identified again during the interviews. Audio recordings were carried out during the face-to-face interviews and it lasted over varied durations depending on the willingness and the settings in which the study was conducted. Overall, the average period for the interviews lasted for about 40 minutes while three interviews exceeded an hour.

Since we sought to generate in-depth information on ADM, we also conducted four FGDs, of which the participants were purposely selected, comprising 8–10 male and female farmers at four different community centres (see Figure 2). During the FGDs, the lead author was sometimes assisted by agricultural extension agents, opinion leaders, or lead farmers in the communities to convene participants to the meeting. During the discussions, the lead author took note of pertinent issues that were mentioned by participants and this was also considered as data for the study. Participants of the FGDs were farmers with different socio-economic and demographic characteristics such as sex, type of farming, purpose of farming, age and specific community. Participants of the FGD had no knowledge about the objective of the study until the discussion began and then the objective of the study was explained to them. Audio recordings were also carried out during the FGDs and the discussions lasted for varied durations.

Step 3: analysis of data generated from step 1 and 2

Field notes were synthesized to deduce relevant responses guided by the research question. This was followed by transcriptions of recordings generated from interviews and FGDs into texts. Transcriptions were read several times to extract keywords, phrases and themes, followed by coding of texts with Atlas.ti which was coded by one person. Coding was carried out by sorting the transcripts under various themes and codes were developed for each line of the text to generate a coding tree (see Figure 3 & Table A2). Some of the themes or codes were identified prior to the coding of the data, while some codes were generated during the process.

Step 4: construction of decision-making table

The codes and themes derived from the data analysis in step 3 were used to construct a decision-making table exhibited as Table 1, in which the decisions made by each individual farmer could be captured. The upper section of the table shows the rainfall record for each month for the year, 2017. Beneath these rows, there is a section which indicates crops selected for each season. Other decision options such as agronomic practices, irrigation, crop protection and other activities are displayed on the rows of Table 1. Hence, if a farmer chooses a crop for a particular season under a specific rainfall condition, there may be the selection of other decision options to support the cultivation of that crop. The use of the figure, 1 or 0 indicates a selection or non-selection of an option in the respective month.

Step 5: interviews with farmers using the decision-making table

In December 2017, 32 farmers (24 men and 8 women) were revisited to generate in-depth knowledge about their decision-making in response to the rainfall conditions with the decision-making table (see Table 1). Farmers were asked to describe how they reacted to the rainfall conditions throughout the cropping seasons for the year 2017. We sought not to treat decision-making of farmers as homogenous. As a result, we interrogated farmers to provide reasons for the decision-making under the variable rainfall conditions. We also interrogated farmers to differentiate between options that were usually selected in each cropping season and the new responses that were selected due to uncertain rainfall conditions in the year 2017. This aspect of the study was carried out using a recall approach. Thus, the limitation of the study was that we relied on farmers' recall of activities throughout the year. Yet, we catered for this limitation by drawing the 32 respondents from farmers who participated in the in-depth interview in step 2 (see Figure 3). In addition, the lead researcher stayed in the communities and took notice of the various decision-making patterns through farm visits.

Step 6: cluster decision-making table into patterns for three seasons

Interviews conducted with the decision-making table for 32 farmers were entered into a spreadsheet. We used the data tab feature in Microsoft Excel from the data generated from step 5 to identify numbers and percentages of farmers who took specific decision-making options under various conditions or the adjustments made during the seasons. We clustered farmers based on similarities in their decision-making, separately for each of the three seasons to distil patterns of decision-making. We manually interrogated the pattern generated to corroborate our findings.

Step 7: identifying adaptive decision-making strategies

The patterns of decision-making and the strategies mentioned by farmers were derived from the transcripts guided by the conceptualization of adaptive decision-making. We carried this out by paying attention to combinations of decision options and cessation of options under different rainfall conditions. We also supported farmers' decision-making strategies with qualitative evidence from the transcripts. Results of the analysis are presented as findings of the study.

Results

We start the section with findings on farming decision-making patterns for the year 2017 for each farming season. This is followed by results on the strategies that were adopted by farmers under uncertain weather (rainfall) conditions, through *flexibility* or *robustness*.

Preseason farming

The farming calendar for a particular year is divided into periods of different lengths. The conventional cropping seasons are April–July (main season) and September–November (minor season) and they correspond with the main and minor rainfall seasons. Due to experiences about uncertainties in rainfall conditions, pre-season farming is carried out to make use of early rains. The cultivation of crops during January–March is what we refer to as preseason farming. It has become necessary to start farming during that period due to experiences of erratic rainfall in the previous years, with many rains in the preseason and lack of them in the main or minor seasons. Therefore, decision-making for farming starts before or in January, with limited knowledge about how much rainfall will be available throughout the year. We illustrate this finding with a quotation derived from FGD conducted in the Toje community where a maize farmer mentioned that:

> Formerly, when we received the first rainfall, we did not use it to plant any crop. We have sown seeds after the fourth or fifth rainfall or after we have celebrated Easter. This has changed and presently, as soon as the rains set in, we start farming, because we do not know what will transpire for the rest of the year. [R9_FGDs, Toje].

For 2017, 87% of farmers cultivated crops in the preseason while 13% did not cultivate any crop. Decision-making for the preseason comprised planting a number of crops: watermelon (50%), green pepper (7%), okra (11%), onion (11%), carrot (14%) and tomato (7%). Each of these crops have some peculiar characteristics suitable for the preseason and they were associated with different decision-making patterns. We analysed the patterns of decision-making for watermelon in the preseason because it was cultivated by most farmers as a relatively quick and drought-resistant crop.

The preseason farming in 2017 was characterized by a false start, with 3 rainy days in January. There was no rainfall in February and a single rainfall event was recorded in March. We observed 5 decision-making patterns by farmers who cultivated watermelon. The decision-making patterns differed in terms of how farmers took into account uncertainty about the weather and selected options as demonstrated in Table 2. With pattern 2.1, farmers took into account uncertainty in the rainfall conditions by cultivating watermelon with other crops (okra, pepper or cassava) on different portions of the same farm or they intercropped it. Several options were introduced on the farm as the rainfall conditions became variable. In pattern 2.2, farmers cultivated only watermelon and suspended farming when there was no rainfall in the month of February and March but they continued after the onset of rainfall for the main season. In pattern 2.3, farmers cultivated only watermelon. However, they responded to the erratic rainfall conditions with manual or mechanic irrigation and selection of other crop protection practices. In pattern 2.4, farmers cultivated watermelon, but they abandoned the crops on the farm during the prolonged dry spell and re-ploughed the land to start cultivation of a new crop in the main season. Pattern 2.5 consisted of farmers who prepared the land in January; yet, they delayed sowing seeds and they ended up not cultivating watermelon in the preseason but in the main season. In three of the decision-making patterns (2.1, 2.2, 2.4) identified in the preseason, we recognized that the cultivation of watermelon extended into the month of May. Hence, the preseason extended for longer than the usual ten weeks growth period.

Main season farming

Although it is stated in the literature (see, for instance, Teye and Owusu 2015) that the main season in the southern part of Ghana is considered to span from April to July, we observed that in the year 2017, it extended to September due to the weather conditions (see Table 3). After preseason farming, crops were selected for the main season and the options available for the main season varied. Tomato and pepper are the main crops that are cultivated in the main season due to erratic rainfall conditions, accessibility to markets and other socio-cultural factors. In the year 2017, the main season was also characterized by uncertainty in rainfall conditions. In this case, farmers experienced rainfall above the

Table 2. Patterns of decision-making for the cultivation of watermelon in the preseason.

Months			January			February		March		April		May	
Rainfall condition			Abnormal			Normal		Normal		Normal		Normal	
Number of rainy days			3			0		1		7		14	
Amount of rainfall			26 mm			-		10 mm		113 mm		201 mm	
Patterns of decision-making						Selection of options							
Pattern 2.1 (21%)	Farm preparation		Sowing of seed	Application of N.P.K	Planted another crop	Weeding	Water	Suspension of farming	Continuation of farming by weeding and application of agro-chemicals			Harvesting	
Pattern 2.2 (42%)	Land preparation	Sowing of seeds	Application of fertilizer	Spraying of agrochemicals	Watering and weeding			Suspension of farming activities	Weeding	Application of second fertilizer	Application of fruit booster	Harvesting	
Pattern 2.3 (11%)	Land preparation		Flooding of the land with water and sowing	Application of N.P.K	Weeding	Watering		Weeding	Harvesting			Cultivation of new crop	
Pattern 2.4 (15%)	Land preparation		Sowing of seeds		Application of N.P.K	Watering	Weeding	Abandoned crops on the farm	Reploughed the farm for main season farming				
Pattern 2.5 (11%)	Land preparation				Delay			Sowing of water melon	Application of N.P.K	Weeding	Application of fruit booster	Weeding	Harvesting

Source: Authors' construct based on field interviews with farmers who cultivated watermelon in 2017 (n = 19).

Table 3. Patterns of decision-making for the cultivation of tomatoes and pepper.

Months	April		May			June			July			August		Sept
Rainfall condition	Normal		Normal			Above normal rainfall			Below rainfall			Abnormal rainfall		Normal
Number of rainy days	7		14			15			10			5		6
Amount of rainfall	113 mm		175 mm			80 mm			78.2 mm			14.2 mm		46.4 mm
Patterns of decision-making								Selection of options						
Pattern 3.1 (14%)	Land preparation	Nursing of	seeds		Transplanting of seedlings local or hybrids		Weeding	Application of fertilizer	Application of fruit boosters	Spraying		Application of 2nd or 3rd fertilizer	Weeding	
Harvesting														
Pattern 3.2 (19%)			Land preparation	Nursing of seed	Transplanting	Application of fertilizer	Weeding	Intercropping/ Diversification of crops	Weeding		Application of fruit boosters	Spraying		Harvesting
Pattern 3.3 (37%)	Delay		Delay			Delay	Land	preparation	Nursing of seeds	Transplanting of hybrid seedlings		Application of fertilizer	Weeding	Application of fruit
boosters	Harvesting													
Pattern 3.4 (30%)	Land preparation		Nursing of local seeds	Transplanting of seedlings local or hybrids		Weeding	Transplanting of hybrid seedlings	Spraying of the farm	Transplanting of hybrid seedlings	Weeding	Transplanting of hybrid seedlings	Transplanting of hybrid seedlings	Weeding and application of 2nd fertilier	Harvesting in batches

Source: Authors' construct based on field interviews with farmers who cultivated tomatoes and pepper in 2017 (n = 32).

requirement of the crops. We analysed decision-making pattern associated with the cultivation of the two main crops: pepper and tomatoes.

The cultivation of tomatoes and pepper was associated with 4 decision-making patterns as illustrated in Table 3. In pattern 3.1, farmers cultivated the local variety in May–July, followed by the cultivation of hybrid varieties. Or, both local and hybrid varieties were cultivated at the same time. Pattern 3.2 is associated with farmers who were involved in intercropping or diversification of tomatoes or pepper on different portions on the farm with other crops. With pattern 3.3, farmers started the cultivation of tomatoes in July while all other patterns described above started in April. Pattern 3.4 was characterized by farmers who transplanted seedlings from the nursery to the farm in batches from the later part of the main season until the onset of the minor season.

Minor season

The minor season usually starts from mid-September to the last week in November. Farmers differentiate between the main and minor season with a usual break in rainfall (records of dry spell conditions) in August. Afterwards, the occurrence of rainfall from September to November is regarded as the minor season. However, findings from interviews and FGDs show that the pattern of rainfall has changed as “below normal” rainfall conditions started before August in 2017. In addition, the amount of rainfall and number of rainy days varied during the minor season. In the year 2017, the rainfall ceased in the early part of July. These phenomena informed farmers decision-making for the minor season as we identified 4 patterns of decision-making represented in Table 4. In pattern 4.1, farmers decision-making involved no cultivation of any new crops. This decision was based on the expectation that there will be no “good” rainfall condition for the rest of the year. In pattern 4.2, farmers tend the crops on the farm to transcend the main season. Pattern 4.2 also connects with pattern 3.4 in the main season and it is mostly cassava and pepper that was left on the farms. In pattern 4.3, farmers tendered tree crop (mango) and harvested it from November to December. Pattern 4.4 comprised farmers who cultivated new crops purposely for the minor season. The crops cultivated for the minor season were okra, watermelon, maize, cassava and pepper. These crops were purposely selected because they could survive in dry conditions. Some farmers intercropped maize, okra and watermelon with beans or groundnut. Farmers who had access to water planted tomatoes, sweet pepper, onions, carrots and cucumber.

Strategies of adaptive decision-making across the three farming seasons

Having described the patterns of decision-making for the three cropping seasons, we now turn to identifying ADM strategies. These strategies are formulated through combining different options from the left side of decision-making table (see page 8) into *flexible* or *robust* strategies. We have identified 6 ADM strategies employed by farmers throughout the 2017 cropping seasons: 3 based on *flexibility* (F1-F3) and 3 based on *robustness* (R1-R3).

ADM strategies based on flexibility

F1: Switching dates for sowing seeds through wait-and-see or delay strategy

Table 4. Patterns of decision-making in the minor season.

Months	September				October		November	December
Rainfall condition	Normal				Normal		Normal	Abnormal
Number of rainy days	6				8		5	2
Amount of rainfall	46.4 mm				70.2 mm		40.8 mm	32.2 mm
Patterns of decision-making			Selection of options					
Pattern 4.1 (6%)	Harvesting of main season crops				No cultivation of any new crops			
Pattern 4.2 (25%)	Harvesting of main season crops				Continual tending of intercrops such as pepper and cassava cultivated in the main season		Harvesting	
Pattern 4.3 (13%)	Spraying mango farm with insecticides		Trimming		Continual tending of mango trees		Harvesting	
Pattern 4.4 (56%)	Land preparation	Cultivation of either maize, water melon, okra, onion, pepper or Cassava	Application of fertilizer	Weeding	Spraying with agrochemicals	Weeding	Spraying with agrochemicals	Harvesting

Source: Authors' construct based on field interviews with farmers in 2017 (n = 32).

The usual decision is to prepare the farmland and sow seeds at the onset of each season. The experiences about unpredictable rainfall conditions caused farmers to switch planting dates or start sowing seeds immediately after a rainfall. For instance, in the year 2017 preseason, the cultivation of watermelon started after Christmas. Some farmers ploughed the farm with the last rainfall from the previous year or the farm was ploughed dry before the occurrence of the first rainfall and then seeds were sown immediately after the first rainfall was recorded. Nevertheless, some farmers adopted a strategy by switching dates for sowing seeds through wait-and-see or delay strategy until the rainfall condition was perceived to be "good" enough to plough or sow seeds. Switching dates for sowing seeds by wait-and-see and delay strategy is based on the assumption that natural variation will provide enough information to understand the consequences of selecting option(s) (Colombo and Byer 2012; Yousefpour et al. 2017). Farmers apply wait-and-see and delay strategy by switching between dates on which they plough the land, sow seeds, or transplant seedlings from the nursery to the farm.

This strategy is selected in accordance with the onset, cessation and occurrence of rainfall in the farming seasons. During the study, the strategy was carried out in the preseason and main season (2.5 & 3.3 in Tables 2 & 3 respectively). Farmers prepared the land; however, they delayed or switch dates for sowing seeds until they have observed and gained enough knowledge that "good" rainfall condition was certain (pattern 4.5 in Table 4). Switching dates for sowing seeds through wait-and-see or delay strategy is *flexible* ADM because farmers can plough the land and refrain from sowing seeds or transplanting seedlings when they observe a "bad" rainfall condition. In some instances, farmers plough the land ahead of the season in response to an impending "dry" condition and then sow seeds at the onset of the rains. Most farmers used their experiential and local knowledge to apply this strategy in response to an impending rainfall condition that has been observed to reduce the cost of production. Therefore, when farmers have not yet sown their seeds or ploughed the land, switching dates for sowing seeds through wait-and-see or delay is one of the strategies that is used especially when their local indicators about the weather and previous decision-making have been less adaptive. These actions reflect flexibility as farmers can reverse or change decision-making easily by not sowing or ploughing when an unfavourable weather condition is observed.

F2: The strategy of muddling through the farming season with the application of various options

In response to unpredictable rainfall conditions during various cropping seasons, some farmers integrated various strategies until they harvested some crops. We refer to this strategy as muddling through flexible ADM strategy because farmers "mix" several strategies or practices and then reverse or change some aspects in response to rainfall conditions. With this strategy, farmers attempt to try out any practice or innovations. This could be the application of different agrochemicals or they mixed various practices in a way that when the weather is favourable they gain something. Alternatively, they withdraw some practices or strategies when rainfall conditions deteriorate or even increase above their expectation. During the preseason, farmers who conducted some manual or mechanized irrigation continued to integrate various agronomic strategies (see pattern 2.3, Table 2). These categories of farmers adopted a "muddling through" strategy in their decision-making because, though they were faced with increasingly "bad" rainfall conditions, they continued in their course of action rather than to abandon it. We found this strategy to be *flexible* ADM as it consisted of continual implementation or redraw of various crop protection strategies such as weedicides, insecticides, herbicides, pesticides and fungicides and different types of fertilizers (N.P.K, urea and ammonia) and irrigation strategies. However, we indicated that the strategy of muddling through adverse rainfall conditions faced some challenges. For example, when there was a dry spell in the minor season, farmers responded to the condition by spraying the farm with some agrochemicals and some of the above-listed strategies. Yet the crops did not yield as expected because high temperatures and other weather conditions affected flowering and fruit formation. In this way, the flexible strategy of continuing to tend the crop can result in escalation of commitment (Drummond 2014), where a more drastic change of course would have been more adaptive.

F3: Alternative irrigation strategies

Farmers depend on the rainfall for farming; however, when rainfall is below the normal condition, alternative options of irrigation strategies were implemented. These include a cup of water applied to the base of each plant at suitable times in the day. Some farmers tied water in perforated plastic bags and deposited it at the base of the plant to mimic a drip irrigation technique. Other farmers manually irrigated their farms with water from a dam, wetland, gutters, pond or drains, with a bucket, or PVC pipeline and a pumping machine. These strategies were carried out either once or twice a day, based on knowledge about evapotranspiration rates, humidity or temperature conditions. This *flexible* strategy faced challenges as well because it could not deal with the very high evapotranspiration rates and temperatures. Farmers who transported water to the farm in plastic bags and water tanks could not continue this strategy after some time due to excessive evapotranspiration and temperatures (see pattern 2.2 & 2.4 in Table 2).

ADM strategies based on robustness

R1: Portfolio strategy of transplanting of seedlings in batches

A strategy which was peculiar to the main season was the transplanting of tomato/pepper seedlings systematically when farmers were not certain about the rainfall pattern for the rest of the year. This portfolio strategy encompassed transplanting of improved variety of tomatoes/pepper seedlings from the nursey in batches with at least two-week intervals from June until August as exhibited in pattern 3.4 in Table 3. In some cases, this strategy was carried out as relay intercropping because seedlings were transplanted after flowering or before the standing crop is harvested. This strategy creates *robustness* in decision-making because in the event of poor rainfall condition, farmers benefited as transplanting was implemented at different periods and sometimes, with different varieties of the same crop. The assumption is that seedlings transplanted without success at one point in time can be compensated by successful seedlings at another point in time. We consider this strategy as an ADM strategy because farmers who encountered unfavourable weather conditions from July to September did not record a total loss as some crops had surpassed the stage they were supposed to be affected by the unfavourable weather conditions.

R2: Selection of robust (hardy) crops or varieties

The selection of crops or varieties of the same crop was carried out carefully in order to generate some harvest or "good enough" harvest. For instance, the "light-green" hybrid variety of watermelon was selected for the preseason due to the notion that it can thrive in poor rainfall condition. In the early part of the main season, farmers selected the local variety of pepper and tomato because they held the perception that they could withstand the heavy rainfall and still bear some amount of fruits (see pattern 3.1). In this instance, farmers avoided a total loss because the selected crops or varieties withstood varied weather conditions; however, they could not generate the maximum harvest. We argue that the selection of *robust* crops for the various seasons is an ADM strategy because they provide a satisfactory harvest in adjustment to variable rainfall conditions.

R3: Intercropping/diversifying crops

Diversification or intercropping was used by farmers to respond to variable rainfall conditions. During the preseason in 2017, some farmers incorporated cassava, okra, maize, or pepper in the watermelon farm (pattern 2.2 in Table 2). The crops are either long duration or drought-resistant varieties. Some farmers also indicated that these crops have "*hard*" leaves to withstand the intense insolation. In the main and minor seasons, garden eggs, okra, maize, cassava, sorghum, millet, cowpea, beans, groundnut and sweet potatoes were used as intercrops (2.1, 3.2 & 4.4 in Tables 2, 3 & 4 respectively). Diversification or intercropping is a portfolio strategy, as farmers used a combination of crops to respond to varied rainfall conditions. We regard intercropping or diversification as a *robust* strategy because the growth of one crop will be partly offset by the loss of other crops. Hence, diversification or intercropping is an ADM strategy as there is a large potential for crops to respond to different conditions. We tabulate a summary of findings on strategies used by farmers during the three cropping seasons in Table 5 with farmers' quotations presented to illustrate the findings and the themes identified in the study.

Discussion

In this section, we explore four areas identified as important in the findings above: levels of decision-making and changes in decision-making due to uncertainties in rainfall conditions; a reflection on how weather information could have supported ADM in farming; ADM affected by the combination of weather conditions and other factors, and types of ADM strategies identified as *flexible* or *robust*.

Our analysis of decision-making in farming in 2017 shows several levels of decision-making. We identified different patterns of decision-making for each cropping season through the use of the innovative decision-making table (see Table 1). However, it is difficult to compare these results with the literature because previous studies have not focused on the use of pattern of decision-making in farming under uncertain rainfall conditions. With regards to decision-making on seasonal basis, we found that farmers

Table 5. Summary of adaptive decision-making strategies identified in the study.

Type of ADM strategies	Definition	Illustrative farmer quote
Flexible ADM F1: Switching dates by waiting-and-see or delay strategy	Wait-and-see and delay in the start of crop cultivation season in ploughing or sowing seeds, based on the assumption that further observation will provide enough information to understand the consequences for selecting a particular crop	*I usually wait and see what is happening and when I see that the weather is not going well then I change my options* [In-depth interview with farmer at Kajanya. In-depth interview 1.12]
F2: Muddling through the farming season with the application of additional options	Dealing with variable weather conditions with various options without specific knowledge about how they will perform	*. . . . I continue with other strategies. As you can see, I have bought agrochemicals and have prepared to do anything so that I can generate some harvest*. [In-depth interview with farmer at Dogo community. In-depth interview 2.5]
F3: Alternative irrigations strategies	Substitute forms of supplying water to the crops when "below normal" rainfall condition is experienced	*Sometimes I draw water from that stagnate water in that wetland . . . .* [II 2.5], *Some of us try to transport water in containers to the farm or draw water with the pumping machine or use the pipe water and these are able to sustain the crops uptill a certain level*. [In-depth interview with farmer at Bedeku-Kpornya. In-depth Interview 3.2]
Robust ADM R1: Portfolio strategy of transplanting seedlings in batches	Selections of multiple dates to transplant the same crop so that it caters for variable weather conditions	*We do not transplant all the seedlings on one date. We do so systematically so that when we transplant tomatoes, at particular date then two weeks' time we transplant again so that when one fails the other ones will survive. [In-depth Interview with farmer at Tobloku Wassakuse. II 3.2]*
R2: Selection of *robust* (hardy) crops or varieties	Selection of options that yield "good enough" outcomes under varied weather conditions	*The thing is that I select a crop that can do well when the rains do not fall again. I have to just weed and then wait for any fruit that will form and that will be my take. But interesting enough, we hardly incur a total loss because by all means, you will harvest some fruits for the household consumption and even manage some for the market [In-depth interview with farmers at Kpodokope. In-depth Interview 1.12]*
R3:Intercropping/diversification of drought resistant crops	Collection of multiple selections of crops or varieties of the same crop to the extent that it accounts for relevant constraints, preferences and uncertainties	*So when the crop was not thriving well in May, I took the decision to intercropped it with maize* [In-depth interview with farmer at Attortorkope. II 1.10]

Authors' construct based on field interviews with farmers in 2017.

cultivated crops in all three seasons or in two of the three seasons. The identification of three farming seasons indicates that decision-making in farming has evolved from the two traditional cropping seasons to include a new cropping season, which we called preseason farming (January–April). Most farmers use the first rainfall in the year to cultivate the watermelon which is a quick and drought-resistant crop. Pre-season farming is innovative because farmers are likely to generate two to three consecutive harvests from different seasons or at least, they are able to generate one harvest for the year when they experience unfavourable rainfall conditions. This finding is consistent with Meinke et al. (2006) who indicated that farmers in 9 Brazilian Nordeste states make use of the first rainfall in the year to start cultivating crops irrespective of knowledge about its continuity. Cafer and Rikoon (2018) also mentioned how farmers planted quickly at the beginning of the year in response to variability in rainfall condition in Ethiopia. Due to the uncertainties associated with the rainfall pattern, decision-making for farming is mostly carried out for the preseason and main season. Farmers indicated that the minor season farming rarely occurs as there is usually little or no rainfall to enable farming. Owusu (2000) and Yaro (2013) had earlier also observed considerable changes in the cropping seasons in the transitional and coastal agro-ecological belt of Ghana due to changes in weather conditions. In addition, the traditional decision-making for the main and minor season is to cultivate crops from April to July followed by the minor season farming (September–November) which is in accordance with the two rainfall pattern in southern Ghana. In our study, we found that decision-making for all the seasons was not carried out distinctly according to the traditional cropping calendar as there was hardly any differences between decision-making for the seasons due to uncertainties in rainfall conditions for the period under study (see Tables 2, 3 & 4). Therefore, though formal weather records may indicate that there are no changes in the patterns of weather conditions, it is important to take note of farmers' daily, weekly and seasonal decision-making in accordance with weather conditions for a specific season or year.

The novelty in the study is the application of *flexible* and *robust* concepts to examine whether farmers' decision-making is adaptive or not based on their account on how they monitored the occurrence of rainfall and the decision-making strategies that they applied. This idea is new as none of the literature on decision-making in response to variability in weather condition, rainfall or climate change have analysed farmers' decision-making in this light. Though some studies also attempted to identify the adaptation strategies of farmers under variable or changing climatic conditions, they have not accessed the flexibility or robustness in the strategies applied (see, for instance, Fosu-Mensah et al. 2012; Wiid and Ziervogel 2012; Yaro 2013; Hoang et al. 2014; Ndamani and Watanabe 2015). We also recognized that studies have indicated farming practices such as intercropping, increasing use of small-scale irrigation methods, diversification of crops and/or varieties on same land, cultivation of new improved varieties, increasing use of agrochemicals, introduction of new crops, changes in crop varieties and in planting times as adaptive strategies that are used to deal with uncertain weather conditions (Armah and Odoi 2011; Fosu-Mensah et al. 2012; Yaro 2013; Ndamani and Watanabe 2015; Tarchiani et al. 2017). These lists of strategies have also been numerously stated in the literature as climate change adaptation strategies adopted by farmers. Yet, there is no clarity on whether these strategies implemented by farmers are *flexible* or *robust* ADM. Hence, the application of the concepts, flexible and robust to examine the strategies of farmers under uncertain rainfall conditions is novel.

The application of *flexible* and *robust* concepts to the case of decision-making in farming in response to uncertain rainfall conditions helped to indicate that strategies such as switching dates for sowing seeds through wait-and-see, delay strategy, muddling through the farming season with the application of portfolio of agrochemical and alternative irrigation strategies are *flexible* ADM. Whereas transplanting seedlings in batches, selection of robust (hardy) crops and intercropping/diversification of drought-resistant crops are *robust* ADM strategies. Farmers applied the ADM strategies either singly or simultaneously to respond to uncertain rainfall conditions. In addition to the list of adaptive strategies which are already mentioned in the literature, we found the selection of robust (hardy) crops as satisficing strategy which can be considered in the list of ADM strategy. Satisficing strategy involves the selection of "good enough" crops to generate a minimum yield under uncertain rainfall conditions (Brownlee 2007). With this strategy, farmers selected some hardy varieties or crops (okra, pepper and cassava), although they may generate low yield under either "above normal" or "below normal" rainfall conditions. Hence, though harvests may not necessarily meet farmers' expectation, they were satisfied with whatever yield they generated under various weather conditions. In this instance, the strategy may not be economically optimal; however, as long as farmers generate some harvest for household consumption or for the market, it was preferred than doing nothing during a particular season. Another innovative strategy identified in the study is "muddling through with the application of various options". We considered this strategy as a flexible ADM as it enabled farmers to select several options to deal with various rainfall conditions. Even so, the continual tending of crops under "bad" rainfall conditions by "muddling through with the application of various options" without any drastic change in decision-making could result in a situation whereby farmers only escalated their commitment (Drummond 2014) in farming. Therefore, in our study, we seek to point out to the scientific community that it is not enough to merely indicate that farmers are taking certain decisions or adaptation strategies in response to changing rainfall conditions. Analysis should extend such discussions towards evaluating its robustness or flexibility.

Third, although farmers used varied *flexible* or *robust* strategies to deal with uncertainty in rainfall conditions, some strategies were less adaptive because most decision-making was based solely on farmers' experiences and local knowledge about the weather. The sole use of experiences and local knowledge about the weather conditions do not provide adequate information to serve as a guide in the selection of crops for the seasons. In the preseason, options were selected under uncertainty because there was incomplete information regarding how rainfall conditions will occur for the period. The result is that the maturation period for watermelon was longer than the usual two months and two weeks growth period. While watermelon without irrigation failed to grow due to the absence of rainfall and other unfavourable weather conditions, the outcome was that some farmers had to plough the land again after almost two months of no rainfall and sow again at the onset of the rains in April (see pattern 2.4 in Table 2). When there is no rainfall, sowing two or three times in a season without harvesting any crop can increase the cost of production or farmers can exhaust their seed reserves. In the main season as well, some farmers perceived that a "normal" rainfall condition will occur; hence, their decision-making was to cultivate a hybrid tomatoes variety from April to June. However, their decision-making was affected by an “above normal” rainfall condition which also affected timely flowering and fruiting (pattern 3.1 in Table 3). From the findings, it can be realized that most farmers could have carried out more ADM if there was some certainty in their experiences and local knowledge about the rainfall and other weather conditions. The availability of tailored weather information for farmers throughout the year could have been useful in enabling the decision-making of farmers (see pattern 4.1 & 4.2 in Table 4) to cultivate new crops or *robust* (hardy) varieties of crops in the minor season since there was an appreciable amount of rainfall and rainy days from September to November. This finding suggests that usable weather information (seasonal, weekly, daily forecast and outlook in the year) tailored specifically for farmers will be important to support ADM in farming. The suggestion is also indicated in various studies conducted by Roudier et al. (2014), Ndamani and Watanabe (2015), Shikuku et al. (2017) and Tarchiani et al. (2017) which also specifies weather information as relevant for the application of adaptive strategies.

Additionally, we found that ADM strategies are a reflection of farmers’ considerations of a combination of rainfall conditions and other factors. These factors include socio-cultural issues, cost of input, selling prices, availability of market, access to assets, social networks, self-perception of farmers, household demography, perceived risks, external institutions, bio-geographical context and socio-demographic factors. These factors enabled or constrained *flexible* or *robust* ADM under uncertain weather conditions. We found that crops such as sorghum, cowpea, beans, or spices could have thrived under “below rainfall” weather conditions. Yet, specific factors such as social networks, availability of land, market, selling prices among others constrained their cultivation even when farmers had the resources to cultivate them under “below rainfall” condition. Hence, in the preseason and main season, farmers’ crop selection was mainly the watermelon and tomato/pepper, respectively, due to some of the above-mentioned factors. Brown et al. (2015), Singh et al. (2016) and Tarchiani et al.’s (2017) also indicated in their studies that household attributes, demographic composition, socio-economic status and external factors (natural resource dependence, market fluctuations, and access to information) can influence ADM in farming.

The outcome of some ADM strategies is immeasurable in terms of yield because the ultimate aim is to generate *robust* or *flexible* options rather than to attain optimal results. Therefore, in the discussion of farmers’ ADM, attention should be focused more on the selection of *flexible* or *robust* strategies and how it can deal with future conditions to avert a total loss. Also, the measurement of the outcome of ADM of farmers can be complex depending on whether it is carried out on individual or collective basis. The outcome of ADM carried out by an individual can be easily identified; yet, the aggregation of the same ADM by numerous farmers or its continual application by an individual for a long term may lead to potentially negative outcome on a large spatial and temporal scale. For instance, a farmer’s response to rainfall conditions at the farm level with continual use of irrigation and agrochemicals can yield a good outcome for the specific season under which crops are cultivated. However, there could be long-term negative environmental outcomes as the land may not be to support food production in a sustainable way. This finding is also identified in Roesch-McNally et al.’s (2017) study on farmers’ adaption intentions under the corn belt climate change scenario. From these findings, we indicate that it is important that sustainability ideas are incorporated into adaptive strategies that are used to deal with uncertain weather conditions (Bhatasara and Nyamwanza 2018). Therefore, farmers and other actors in the agricultural sector ought to prioritize sustainable strategies in response to variability in weather conditions in a sustainable manner.

With regards to the contribution of our study to theory, we derived ADM strategies from the patterns of decision-making. The application of the concept yielded positive results because it enabled the identification of useful strategies. We added value to the concept by examining decision-making at the individual level, whereas ideas on ADM are mostly discussed at the organizational level under deeply uncertain future climate change scenarios. This implies that the concept of ADM is not limited to organizational decision-making at district, municipal, national or regional levels. For future research, the concept can be developed further by building on the temporal dimensions (proactive and reactive ADM) with the two types of ADM developed for this study. In addition, the flexible nature of the concept can enable it to be combined with other concepts such as naturalistic decision-making (Zsambok and Klein 2014), intuitive decision-making (Klein 2003; Lunenburg 2010), logic of appropriateness (March 1991; March and Olsen 2011) and logic of consequentiality in decision-making (March 1994). Therefore, we suggest that future research on adaptive decision-making should consider repeated analysis with the decision-making table (see Table 1) for multiple years in order to improve insight on farmers' ADM and learning outcomes. This can help to determine whether ADM of farmers is passively or innovatively carried out. Further research is also required on how ADM is affected by a combination of factors such as age, level of education, membership to farmers' groups, household size, sex, type of farming, availability of weather information and sources of water for farming under uncertain weather conditions.

Conclusion and implications

This study examined patterns of farming decision-making under uncertain water availability conditions and identified adaptive decision-making strategies. We conceptualized ADM as a pattern of decisions that is characterized by the application of decision options that are *flexible, robust* or both in response to uncertain socio-technical-environmental conditions. From our analysis of farming decisions in the Ada East District (Ghana), we identified six different decision-making strategies in response to the variable rainfall conditions. The three flexible adaptive decision-making strategies are: switching dates for sowing seeds through wait-and-see or delay strategy, muddling through the farming season with the application of various options and alternative irrigation strategies. The three robust adaptive decision-making strategies are portfolio strategy of transplanting seedlings in batches, selection of robust (hardy) crops and intercropping or diversification of crops. Based on how farmers select strategies in response to uncertainty in rainfall conditions, we argue that some decision-making strategies are more adaptive than others.

In conclusion, results on ADM strategies in farming have implications on the promotion of ADM in farming, the provision of information and other resources for farming. First, considering global demand for food and challenges farmers face in producing food under increasingly uncertain climatic conditions, it is important to develop and enhance capacities for ADM. This can be achieved by formulating sound strategies on

ADM in farming policies and field extension guidelines, such that flexibility and robustness can be built into farming decisions. Second, there is an urgent need for location-specific, timely and relevant weather information for agricultural regions that are noted for variable weather conditions. The timely provision of weather information with outlooks throughout the season can enable farmers to adapt their farming strategies under various weather conditions. Additionally, extension workers, radio channels, lead farmers, input dealers and the farming community can also work together to provide collaborative assistance for farmers on expected rainfall and ADM strategies. This would help to provide answers to farmers' questions on: how much rain to expect for the season; the possibilities of dry spell during the season; whether or not to start farming; selection of crops and varieties; and opting for other livelihood strategies in response to a weather forecast. The provision of information on the weather and ADM strategies should also take into account farmers' culture, traditions, economies and availability of resources. Third, the communication of information on ADM strategies should not only concentrate on implications for harvest, which borders on economic gains but also implications for the sustainability of other livelihood capitals such as natural and physical resources (e.g. soil quality, soil moisture retention, etc.). Furthermore, programmes on the distribution of seeds and other agricultural inputs should be timely implemented before the onset of the season for ADM. Similarly, the distribution of seeds and other agri–inputs can be targeted at areas where farmers' decision-making failed under "bad" weather conditions during previous seasons.

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Appendix A

Table A1. List of interviewees.

Agricultural Extension Agents (AEA)	Interviews under extension agents	Date	Name of community	Gender	Irrigation/ rainfed	Purpose of farm production
AEA 1	II 1.1	19/6/2017	Attortorkope	Male	Both	Commercial
	II 1.2			Male		Commercial
	II 1.3	16/7/2017	Dogo	Male	Rainfed	Semi-commercial
	II 1.4	21/06/2017		Male		Semi-commercial
	II 1.5			Male		Semi-commercial
	II 1.6			Male		Semi-commercial
	II 1.7	26/9/2017	MacCarthykope	Male	Both	Commercial
	II 1.8	21/06/2017	Adornorkope	Male	Both	Commercial
	II 1.9	15/06/2017	Tovie	Female	Rainfed	Semi-commercial
	II 1.10	18/6/2017	Angorsekope	Male	Irrigation	Commercial
	II 1.11	29/8/2017	Wasakuse	Male	Rainfed	Semi-commercial
	II 1.12		Wasakuse	Female		Subsistence
AEA 2	II 2.1	12/07/2017	Kajanya	Male & Female	Rainfed	Subsistence
	II 2.2	13/07/2017		Male		Commercial
	II 2.3	12/07/2017	Tamatoku	Female		Commercial
	II 2.4	18/7/2017		Female		Semi-commercial
	II 2.5	20/9/2017		Male		Subsistence
	II 2.6	13/7/2017	Amaneykope	Female		Semi-commercial
	II 2.7			Male		Commercial
AEA 3	II 3.1	20/6/2017	Bedeku	2 Males	Rainfed	Commercial
	II 3.2		Kasseh	Male		Commercial
	II 3.3		Korlekope	Male		Commercial
	II 3.4		Bedeku-kpornya	Male		Semi-commercial
	II 3.5			Male		Semi-commercial
	II 3.6	29/8/2017	Lufenya	Male	Rainfed	Semi-commercial
	II 3.7			Male	Rainfed	Semi-commercial
AEA 4	II 4.1	19/7/2017	Anyarkpor	Female	Irrigation	Commercial
	II 4.2			Female		
	II 4.3		Ada Foah	Male		
	II 4.4			Male		
	II 4.5			Male		
	II 4.6	10/8/2018	Totimekope	Male		
	II 4.7	31/7/2017	Mataheko/ Ocanseykope	Male		
	II 4.8			Male		
	II 4.9			Male & Female		
	II 4.10			Female		
AEA 5	II 5.1	28/6/2017	Detsekope	Male	Rainfed	Commercial
	II 5.2	27/06/2017	Toje	Male		Commericla
	II 5.3			Female		Semi-commercial
	II 5.4			Male		Commercial
	II 5.5			Female		Semi-commercial
	II 5.6	28/6/2017	Asigbekope	Male		Semi-commercial
	II 5.7	28/6/2017	Kpodokope	Male		Commercial

Table A2. Code list.

Codes	Answers the question:
Seasons	**Periods for the cultivation of crops and it coincides with the occurrence of the rainfall**
Preseason	
Main season	
Minor season	
Rainfall conditions	**Descriptions of the occurrence of rainfall**
Above normal	Rainfall condition comprising of more than 15 rainy days in a month
Normal	5–14 rainy days in a rainy season
Below	When 0–3 rainy days is recorded in a rainy season
Abnormal	The record of rainy days in a dry season or month
Bad weather	The occurrence of above or below rainfall condition
Good weather	Normal rainfall conditions in the farming seasons
Crop selections	**Decision-making on type of crops selected for the a specific season**
Preseason crop selections	
Main season crop selections	
Minor season crop selections	
Option	**Collections of usual decision-making for the farming seasons**
Ploughing	Eg. Use of tractors to plough the land
Harrowing	
Land preparation	Eg. Burning of weeds and tree stumps
Sowing of seed	
Nursery	
Transplanting	
Irrigation strategies	Eg. Carrying water to the farm
Application of 1st, 2nd, 3rd Fertilizers	Eg. N.P.K, Ammonia or Urea
Thinning	
Weed control	
Pest control	
Spraying	Eg. Application of fruit boosters or insecticides
Soil moisture conservation	Eg. Application of cow dung or manure
Harvesting	
Flexible decision-making strategy	**What plans do you make after the rainfall or when there is no rainfall in the season?**
Decision-making strategy: Muddling through	
Decision-making strategy: Irrigation	
Decision-making strategy: Wait-and-see/delay	
Robust decision-making strategy	**Type of plan used by a farmer to support growth of crops during too much or too little or dry spell condition**
Decision-making strategy: Drought resistant	
Decision-making strategy: Short duration cultivars	Crops that matures 2 months or less eg. water melon
Decision-making strategy: Starting early	eg. Planting immediately after Christmas
Decision-making strategy: Portfolio of agrochemicals	eg. Fungicides, pesticides, insecticides, categories of feritlizers, weedicides, herbicides
Decision-making strategy: Divers planting dates	
Decision-making strategy: Transplanting in badges	At least 2 weeks intervals between transplanting dates
Decision-making strategy: varieties of seeds	
Decision-making strategy: Varieties of seeds of the same crop	Eg. Tomatoes has seminis, pecto mech, local cultivars etc.
Decision-making strategy: Switching crops between seasons	
Decision-making strategy: Diversification	
Decision-making strategy: Intercropping	