TOWARDS BUILDING DROUGHT RESILIENCE OF RICE PRODUCTION IN CAMBODIA: FROM A SYSTEM DYNAMICS PERSPECTIVE

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ABSTRACT

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The future of Cambodia's rainfed rice cultivation is associated with high risks and uncertainties in the face of climate change. The projected increases in drought frequency and its uneven distribution over seasons and across places due to climate change coupled with low adaptive capacity of rural farmers speaks to the necessity to build drought resilience across the country. The main objectives of this study were to identify sources of drought resilience at household and commune levels and to find possible ways to improve resilience to drought. To meet the objectives, a system dynamics model for drought resilience was developed. Data from household survey were used to estimate major model input variables through descriptive statistics, to define farm household typology through two-step cluster analysis, and to estimate relation between variables using multiple regressions. The results of the study show that access to irrigation is the most important source of resilience at both household and community levels. Improving access to irrigation to the threshold level of approximately 40% can help maintain stability and continuous development of rice production over time. Another important source of drought resilience is agricultural diversification such as spatial diversification of paddy lands and varietal diversification. The group of farmers that is resilient to drought is associated with this characteristic as depicted in the linkage between farm typology and model outputs. On the other hand, nonfarm diversification such as remittance from migration and local wages can be other sources of resilience to drought. However, it is to be noticed that the resilient group of farmers is associated with an average degree of dependence on both rice and nonfarm incomes, denoting that depending too much on nonfarm income might draw resources away from agriculture.

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1. Introduction

1.1. Background and problem statement

Cambodia's economy largely depends on agriculture as this sector contributes up to 32 per cent of the country's GDP and employs approximately 64 per cent of the country's total labor force (ADB, 2014). Roughly 80 per cent of the population reside in rural areas and depend primarily on rice cultivation for their livelihoods (USDA-FAS, 2010). According to USDA-FAS (2010), rice is cultivated over approximately 85 per cent of the total cultivated area, of which only 14 per cent is irrigated. Being an important source for rural livelihoods, rice is also a staple food for the Cambodian diet and consitutes 65 to 75 per cent of the total daily energy needs (Yu & Fan, 2009). Despite the importance of rice farming for rural livelihoods, the majority of Cambodian farmers still practice traditional farming techniques and grow rice for subistance, just one crop cycle per year (Ros, Nang, & Chhim, 2011).

As rainfed rice production in the wet season accounts for most of the total rice production in Cambodia, the highly erratic rainfall patterns associated with regular occurances of exteme climatic events such as flood and drought (USDA-FAS, 2010) can leave agricultural production of the country with continuing uncertainties in the face of climate change. In the agricultural sector, drought apparently is the most experienced natural shock for Cambodian farmers (Thomas et al., 2013). The very liklely shift in rainfall patterns suggested by climate change projections (Mcsweeney, New, & Lizcano, 2008), coupled with low adaptive capacity of rural farmers in almost every province (Yusuf & Francisco, 2009) makes the rice sector in Cambodia highly vulnerable to climate change, which requires building drought resilience.

There are several reasons why building drought resilience in Cambodia is crucially important. First, drought is a recurrent crisis whose accumulative impacts can put farmers' livelihood under pressure over time. The impacts of drought are multifaceted including reduced crop production, reduced income, increased unemployment and migrations (Wilhite, Svoboda, & Hayes, 2007), reduced consumption, selling productive assets and so on (Pandey, 2007). In general, the indirect impacts surpass the direct ones, which is why attention is usually less paid by both farmers themselves and policy makers compared to other hazards (Wilhite et al., 2007). However, the accumulative losses caused by drought over time can be tremendous and would collapse farmers' livelihood system. For instance, in Cambodia a June 1994 drought affected 5 million people (almost 50% of population in Cambodia during that time) and caused economic losses of 100 million USD (EM-DAT, 2014). Second, building drought resilience is a climate-smart strategy in response to climate change because drought is naturally a slow-onset hazard. It creates stress on farmers' livelihood over time, but this gradual process of accumulating impacts can also allow farmers to have more time to respond to and recover from it. Third, there is evidence that drought events and their magnitudes in Cambodia has increased over time. For instance, counting from 1950 to 2005, the probability of occurrence of a drought event in Cambodia is around 0.34(Pandey, 2007), meaning that an average drought could occur once every three years.

If climate change projections for Cambodia depicting increases in extreme climatic events such as drought (Mcsweeney et al., 2008) are accurate, building drought resilience in Cambodia is a priority that requires involvement from all relevant stakeholders. Because uncertainties of risks imposed by unpredictable natural shocks cannot be completely eliminated (Berkes, 2007), it is necessary to learn to live with these changes and uncertainties and build capacity to deal with them, while sustaining and enhancing livelhood at the same time.

Resilience is defined by (IPCC, 2012) as "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions" (p. 5). Resilience manifests at multiple scales such as individual, household, community, and systems levels (Béné, Wood, Newsham, & Davies, 2012) and there are multiple sources of resilience at each of these levels (W. Neil Adger et al., 2011). Furthermore, in social-ecological system perspective, the responses to a particular risk may adversely impair the capacity of the system to cope with other risks (W. Neil Adger et al., 2011). Thus, to enhance resilience, i.e. reduce vulnerability, in the face of unexpected changes and uncertainties of climate extreme such as drought, for example, it has to understand resilience as a multifaceted and multiscalar concept.

1.2. Research Questions

The main purpose of this study was to understand if the responses of farmer communities exposed to recurrent drought hazards lead to greater resilience or greater vulnerability. To meet this objective, the following research questions need to be answered.

- What are the sources of resilience to drought at household and community levels?
- What are the factors and/or processes that make a group of households more or less resilient to drought than another?
- How do these factors and/or processes influence drought resilience at the community level?

1.3. Study Area

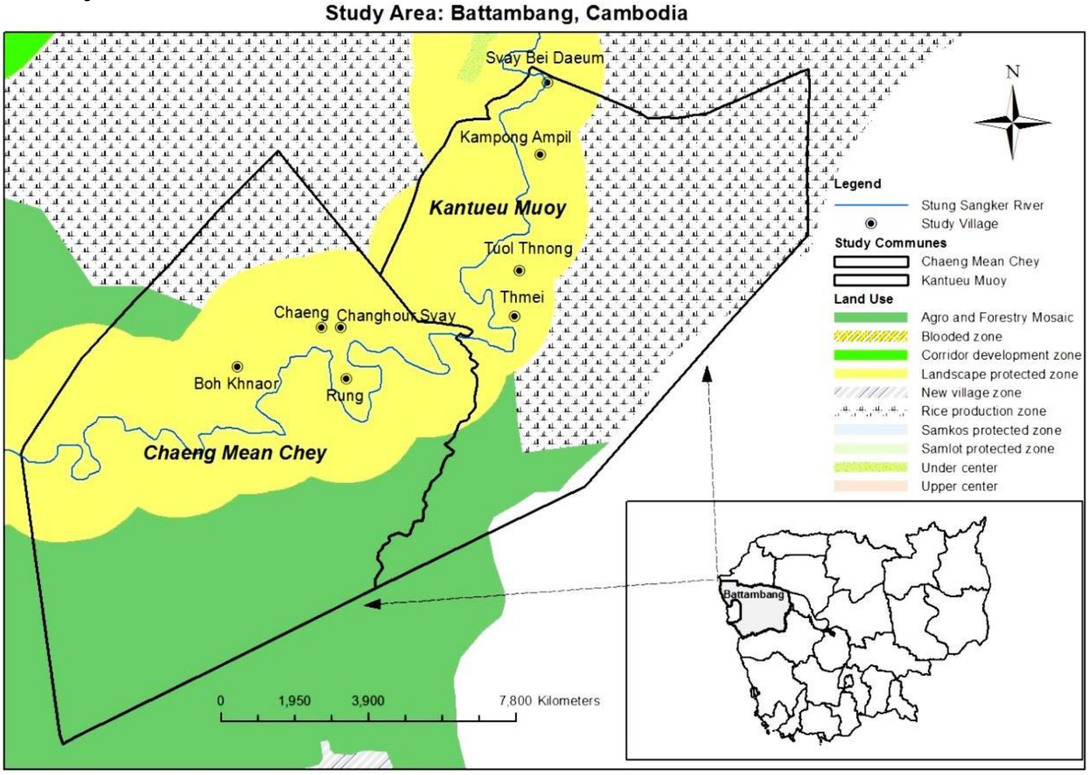

Figure 1: Study area, Battambang province, Cambodia

Two communes of Bannan district in Battambang province of Cambodia, namely Chaeng Meanchey and Kanteur Mouy, were selected for this study. These communes are crossed by Stung Sangker River, which contains several streams. The total population of these two communes was 14349 in 2010, with 2998 families (Table 1), the majority of which have rainfed rice farming as primary occupation (Table 2). In average, active labor was approximately 49 per cent of the total population and migration rate was around 3 per cent of the active labor (Table 1). In these communes, the average wet rice yield ranged from 1.0 to 2.5 hectares and varied from year to year (Table 2).

Table 1: Demography of study communes

Communes	Population	Number of families	Active labor	Migration rate
Chaeng Meanchey	9,296	1,806	48.5%	1.9%
Kanteur Mouy	5,053	1,192	49.0%	5.2%
Total	14349	2998	49.2%	3.1%

(NCDD, 2010)

Table 2: Rice farming in the study communes

Communes	Wet rice land area	Average yield	Rice farming as primary occupation	Average rice price
Chaeng Meanchey	5062.00 ha	1.50 tons/ha	80.00%	0.20 USD/kg
Kanteur Mouy	4667.00 ha	1.00 tons/ha	79.00%	0.20 USD/kg
Total	9729.00 ha	1.25 tons/ha	79.50%	

(NCDD, 2010)

In these study communes, the average age of the population was about 30 years and 50 per cent of them were aged 25 years or less (Median=25). Moreover, in general people had very low education. For instance, in average people spent 4 years or fewer in school. On the other hand, for the household sample, the average household size was about 5.5.

Table 3: Respondent profile

	N	Min.	Avg.	Max.	Median	St.Dev.
Age	545	1.00	29.88	86.00	25.00	19.52
Education	545	0.00	4.36	15.00	4.00	3.59
HH size	99	1.00	5.56	11.00	5.00	2.11

Table 4 shows the main household occupations of the household sample. Given that a farm household may have more than one occupation, based on percentage of responses, the five most important household occupations include rice farming, crop growing, livestock, local wage labor, and migration. The other sources for livelihood include growing vegetables, small business and salary.

Table 4: Main household occupations

	N	Minimum	Maximum	Mean	Std. Deviation
Rice farming	99	0.00	1.00	0.99	0.10
Growing crop	99	0.00	1.00	0.60	0.49
Livestock	99	0.00	1.00	0.54	0.50
Local wage	99	0.00	1.00	0.47	0.50
Migration	99	0.00	1.00	0.36	0.48
Growing vegetable	99	0.00	1.00	0.29	0.45
Small trade	99	0.00	1.00	0.12	0.32
Salary	99	0.00	1.00	0.12	0.32
Valid N (listwise)	99				

2. Review of Literature

Resilience has gained popularity among different communities of scholars and development communities; however, it has yet not received a broadly agreed upon definition. One reason is due to an attempt to broaden the resilience concept from its original narrow definition in Ecology into a more integrative one. The term is rooted in the discipline of Ecology (Holling, 1973), expanded in the social sciences (W.N. Adger, 2000) and further integrated in social-ecological system researches (Folke, 2006). Another reason is because of different disciplinary focuses in research areas. For instance, the early definition of resilience proposed by Holling (1973) places importance on the capacity of an ecosystem to maintain its stability and function in the face of changes and disturbances, while from a social science perspective resilience definition is centered around maintaining and improving livelihoods, while responding to social and environmental changes through appropriate institutions (W.N. Adger, Kelly, Winkels, Huy, & Locke, 2002). On the other hand, from a social-ecological system perspective, resilience encompasses not only the amount of disturbances the system can tolerate, while retaining its structure and functioning, but also the capacity to self-organize, learn and adapt (Carpenter, Walker, Anderies, & Abel, 2001).

Different schools of thought also define resilience in different ways. Because hazard research tends to focus more on the magnitude of a hazard's impacts and degree of recovery, resilience rests on capacity of social and physical system to minimize disaster impacts, pre- and post-disaster measures, and how fast the system can recover from the hazard (Cutter et al., 2008). On the other hand, in the climate change community, resilience is defined as "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions" (Lavell et al., 2012). Despite being broadly defined, this definition encompasses the capacity of the system to moderate impacts of hazards, degree of recovery from those impacts, and capacity to maintain system stability. For development communities, resilience not only includes similar characteristics as defined by hazard communities, but is also linked to vulnerability reduction, while promoting growth. For instance, in policy and program guidance for building resilience to recurrent crises, USAID (2012) defines resilience as "the ability of people, households, communities, countries, and systems to mitigate, adapt to, and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth" (p. 9).

Despite inconsistencies in using key terms to characterize the attributes of resilience and some differences in disciplinary focus, there are commonalities that can be drawn from. First, resilience is characterized by three sets of capacities: absorptive capacity–the capacity to moderate impacts of shocks and stresses so as to maintain system stability; adaptive capacity–involving incremental adjustment and social learning based on an understanding of changing conditions; and transformative capacity–the capacity to make systemic change in a positive way when the old system is no longer viable (Béné et al., 2012). The combination of these three sets of response capacities marks the resilience concept as a paradigm shift from the traditional perspective, which believes that changes in systems should be controlled, to a philosophy accepting that social-ecological systems are adaptive systems and humans have the capacity to learn from, live with, and adapt to uncertainties and unexpected changes. Second, resilience manifests at multiple scales such as individual, household, community, and systems levels (Béné et al., 2012) and there are multiple sources of resilience at each of these levels (W. Neil Adger et al., 2011). Furthermore, the responses to a particular risk may adversely impair the capacity of the system to cope with other risks (Adger et al., 2011).

There are numerous discussions by different communities of scholars about two major approaches to resilience building: specified resilience and general resilience, and on which one is more appropriate for studies of resilience to hazards. To understand system resilience in a practical manner as well as to identify measureable indicators of resilience, it is important to consider resilience as context-specific (Walker1a & Carpenter, 2002). In doing so, it is necessary to clearly determine which part of the system should be resilient and is resilient to what type(s) of disturbance because system resilience may manifest in one time period at the expense of resilience in the following period, and the resilience at a specific spatial scale may be inherited from a broader scale (Carpenter et al., 2001). Identifying particular aspects of the system that should be resilient to certain kinds of disturbances can help us to discover system feedback loops whose processes can explain the pathways of system resilience in a practical manner (Bennett, Cumming, & Peterson, 2005). However, when focusing too much on a particular aspect of system resilience, there is a risk of undermining the whole system's resilience in other ways (Folke et al., 2010).

Thus, to provide the best compromise between differences in defining, conceptualizing and operationalizing resilience, there are three factors to be taken into consideration for framing resilience. First, resilience needs to have a general basic definition that can capture the robustness of this concept in a development context (Béné, Newsham, & Davies, 2013). Second, it is important to consider the type (slow or rapid onset) and characteristics (social or natural origin) of hazards/disturbances of interest when measuring and framing resilience. For example, the slow-onset disturbance such as drought has very different indicators for measurement from rapid-onset one. It also requires relatively different capacities of response and allows longer recovery time. Plus, human communities have no capacities to halt or completely remove this kind of disturbance, but must learn to live with and to respond to it while continuing and improving their livelihoods. In contrast, disturbances of social origin such as health shock or chronic poverty depend more on human ability to remove these negative impacts. People can eliminate or completely remove them given their own response capacities and the context in which the community is located. Last but not least, it is necessary that there is at least a conceptual link between definition, conceptualization, and measurement of resilience.

3. Methods

3.1. Formulation of conceptual model for drought resilience

This study adopts the definition of community resilience introduced in Frankenberger, Mueller, Spangler, & Alexander (2013) as "The general ***capacity*** of a community to ***absorb change***, ***seize opportunity to improve*** living standards, and to ***transform livelihood systems*** while sustaining the natural resource base." The community in this context refers to a commune which is the lowest level of governance in Cambodia and defined by political boundary. The term "resilience" is conceptualized following Béné, Wood, Newsham, & Davies (2012) as composing of three types of capacity: ***absorptive capacity*** – the capacity to moderate immediate impacts of drought through preventative measures and short-term coping strategies; ***adaptive capacity*** – making proactive and long-term decisions about alternative livelihood strategies through incremental adjustment and social learning based on an understanding of changing conditions; and ***transformative capacity*** – the capacity to make systemic change given the fact that the old one is no longer viable. Community resilience is not simply the sum of these three types of capacities but the outcomes of interplay between them through certain processes of responses.

The conceptual framework for this study is based on the synthesis of two different approaches: ***livelihoods approach*** (Scoones, 1998) – focusing on access to and distribution of productive assets within the community through institutional structures and processes to pursue major livelihood strategies; ***Disaster Risk Reduction approach*** (Cutter et al., 2008) – placing the importance on recovery activities and time to respond to drought impacts. For instance, during the drought period, the immediate impacts of drought are moderated through absorptive capacity at household and/or community level. If not completely absorbed, the remaining impacts may be further reduced through the long-term adaptation mechanism (adaptive capacity). If the residual impact still remains beyond community capacity to survive, transformation of the livelihood system is needed. To know when transformation would take place, it is necessary to look at the degree of recovery (measured as a time scale) from the drought impacts. If the recovery time is too long (low degree of recovery) extending almost close to the next occurrence of hazard or to the extent that the community can't bear, partial or full transformation of the system is required. The conceptual model presented in Figure 2 was modified from Béné et al. (2012), Cutter et al. (2008), Frankenberger et al. (2013) and Scoones, (1998).

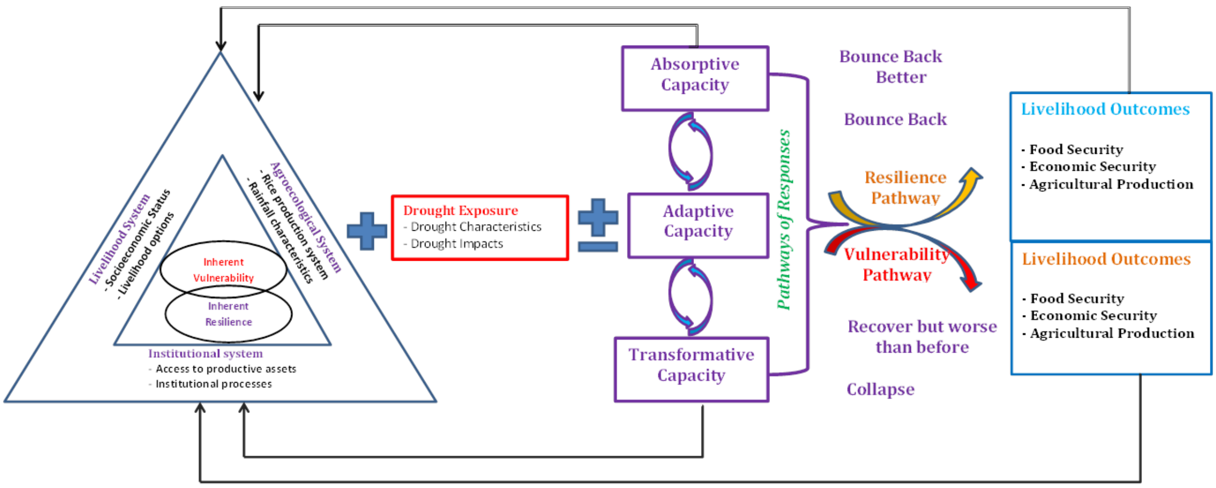

Figure 2: Conceptual model for drought resilience

3.2. Field data collection

This study used both primary and secondary data. The secondary data such as migration rate, percentage of active labor, and commune's total cultivated area were extracted from commune database online (NCDD, 2010), while rainfall data was obtained from the provincial department of agriculture. The primary data were data from focus group discussions and household surveys, conducted respectively in February and April 2015.

Two focus group discussions were conducted in Kanteu Mouy and Chaeng Meanchey communes of Battambang province and in total there were 20 participants including the commune chief, village chiefs and farmer representatives. The focus group discussions collected data about available water sources, drought characteristics and drought impacts on livelihood and rice cultivation, and farmers’ use of agricultural inputs. The data from group discussions were used to modify the causal loop diagram developed for drought resilience as well as to design the household questionnaire.

The household survey was conducted in the two communes and in total four villages in each commune were selected. The surveys were administered to the household head or his/her spouse, while the unit of analysis was the household. The sample size was 99 and the population was 2998 households. The sample was purposively selected based on characteristics of farmers who had different livelihood options such as rice cultivation, crop cultivation, local wage, and migration, and who were affected differently by the 2014 drought.

3.3. Development of causal loop diagram and system dynamic model

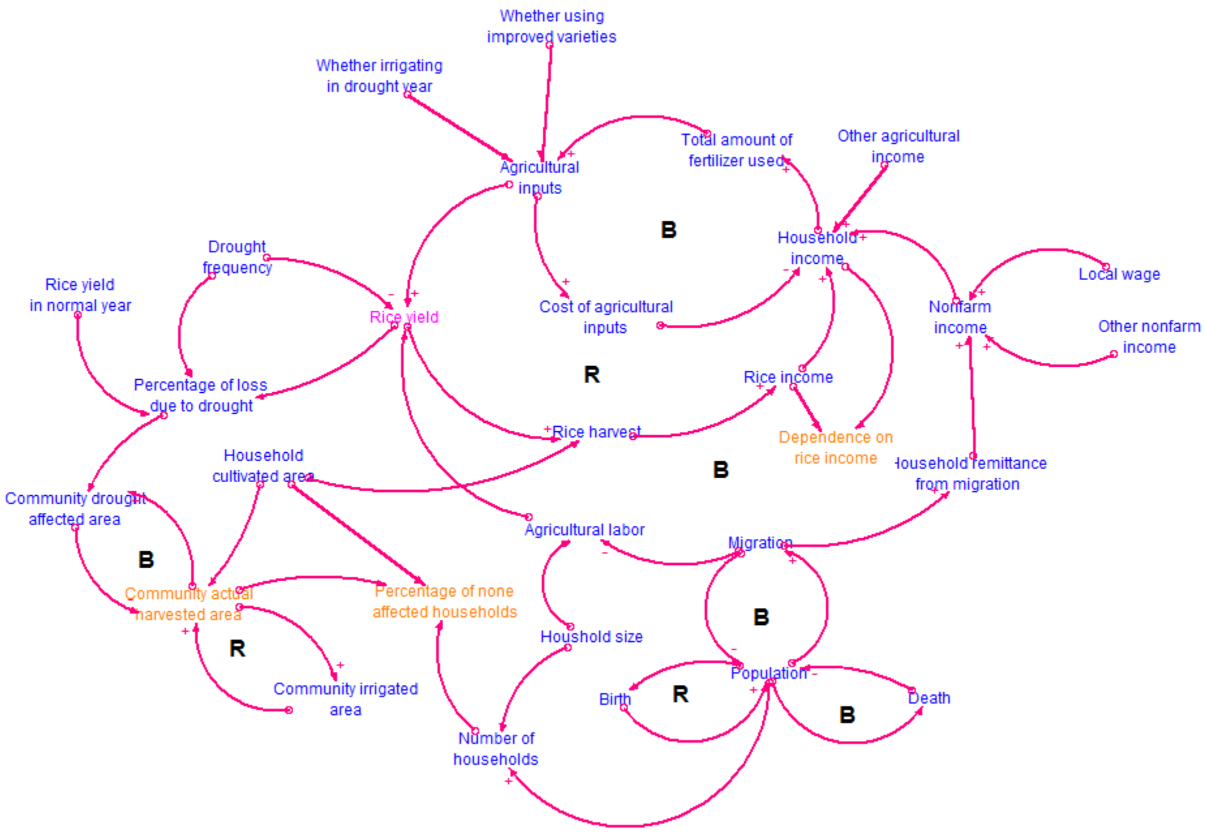

Figure 3: Causal loop diagram depicting drought resilience

Causal loop diagramming is an important tool in system dynamics. It depicts a set of feedback loops that explain complex interactions between actors, action of responses or information. The research questions, thus, can be depicted through diagram above (Figure 3). This causal loop diagram was developed based on contextual understanding of the study area and the nature of the problem, information from focus group discussion, and survey data. There are three major feedback loops in this diagram.

In the first feedback loop, four agricultural inputs (whether irrigating in drought year, whether using improved varieties, fertilizer used per hectare, ratio of agricultural labor to household size) positively affect rice yield. If any of these inputs are increased, rice yield will go up, which then increases the annual rice harvest. The more rice harvest, the more rice is sold, which then increases household income. When household income increases, more fertilizer is used, which will then increase rice yield. This is a reinforcing feedback loop.

However, in the second feedback loop, the increased use of agricultural inputs are associated with increased costs, for example, cost of irrigating, cost of buying seeds for those who use improved varieties, and cost of buying fertilizer. When the costs of agricultural inputs are increased, the household income is reduced, which then leads to less money available for investing in agricultural input use. This is the balancing feedback loop.

In the third feedback loop, out-migration brings back remittances, adding to household income. When farmers have more income, they are more likely to invest in agricultural inputs, which then increases rice yield. When rice yield increases, farmers see a good opportunity to invest in agriculture and they attract agricultural labor, which then reduces number of out-migrants from the community. This makes a balancing feedback loop.

A system dynamics model was developed based on this causal loop diagram following the developed conceptual model/framework for drought resilience (Figure 2) to address the above research questions. The system dynamic model that was developed is described in Appendices 3 and 4.

System dynamics modeling (SDM) is a methodology as well as a tool. The rationale for using this modelling approach for aiding decision making processes is threefold. First, the model makes it possible to identify the potential thresholds beyond which the current state of system in consideration tips into the new state which can change the function and structure of the system--for example, the point at which households transform their current livelihood or production system to a new one in response to a shock. Second, SDM can help figure out which underlying factors contribute to enhancing or eroding system resilience, from which we can provide insights into how adaptive and transformative capacity can be built to enhance the system resilience to unexpected shocks. For instance, the model allows us to test which parameters/variables are very sensitive to change of the outcome variables being investigated. On top of that, the robustness of using SDM is that it creates new opportunities for understanding the degree of recovery and re-organization after disturbances to a system. For example, the model simulation enables comparison between different communities regarding how fast or slow they recover from a drought hazard.

3.4. Description of important model inputs/variables

- Drought and normal year definition

Table 5: Descriptive statistics of rainfall

N	Valid	18
	Missing	0
Mean		1277.49
Median		1296.10
Std. Deviation (SD)		203.21
Minimum		907.10
Maximum		1707.40
Percentiles	25	1079.32
	75	1439.27

A drought year in this study is defined as the year that has rainfall value below (Mean-1*SD) mm, which is equal to 1074.3 mm in this case, while a normal year, the non-drought year, is the year that has rainfall value higher than this. Mean annual rainfall is the long-term average value. From this assumption, for the 17 years of rainfall data available the probability of drought occurrence is 0.28, which is very close to the overall probability of drought occurrence in Cambodia, as indicated by (Pandey, 2007). That is to say it is likely that drought occurs every three years. 2014 is the most severe drought year according to the rainfall data and data from survey, while 2013 is a normal year, the year when the communes received enough rain for rice cultivation.

- Yield estimation for drought and normal year

Because agricultural inputs respond differently to yield in normal and drought years, two different yield-input relationships for normal and drought year were estimated. In this study, annual rice yield was estimated using multiple regression, where yield is the dependent variable and four agricultural inputs (agricultural labor, access to irrigation, amount of fertilizer used, and varieties used) are independent variables. The details for estimation of multiple regressions are presented in Appendix 1.

- Relationship between household income and total fertilizer used

This relationship was estimated using linear regression based on the assumption that the more household income the farm households earn, the more likely they invest in agriculture, i.e. in fertilizer. This is indicated in the causal loop diagram. The details for estimation of this relationship are presented in Appendix 2.

- Other variables

The other variables represented in the model and their relations/equations are listed in Appendix 3.

3.5. Data analysis

Data analysis has two parts. The first one involved constructing relations between variables. Both qualitative and quantitative data were used in this study. Qualitative data included data from focus group discussion and in-depth interviews, while quantitative data were data from household survey and data from commune database online (NCDD, 2010) for Cambodia. Data from focus group discussions and in-depth interviews provided contextual understanding about farmers' uses of agricultural inputs and drought responses, which is very useful for informing the casual loop diagram and model structure development. Data from in-depth interview and group discussion were also used to explain reasons behind certain outputs produced by model simulation. Survey data and data from commune database online were very important sources for model input variables and estimation of some important relationships between variables. Survey data analysis was performed using descriptive statistics for understanding major model input variables, multiple regression for estimating relationship between rice yield and usage of agricultural inputs, and cluster analysis for defining farm household typology on which the model simulation scenario was run.

Farm typology was defined based on the attributes of agricultural inputs a household possesses, using two-step clustering method, a built-in function in SPSS. This model (Figure 5) used Log-likelihood method for distance measure and Schwarz's Bayesian Criterion (BIC) for clustering criterion. The input variables for the model were of categorical and continuous. Evaluation fields such as rice yield in normal and drought years and percentage of yield loss due to drought were also included in the model, but they were not used as clustering criteria. The rationale for developing the farm typology was to understand which group of farmers perform better or worse off during normal and drought years, and under what processes. This classification was used as criteria to determine input variables as well as to run the simulation.

The second part involved analysis and interpretation of model simulation outputs by comparing different groups of farmers as defined in a typology classification run on certain aspects such as rice yield, net rice income, household income, yield recovery, dependence on farm and nonfarm income, and percentage of yield loss. At the commune level, actual harvested area and percentage of drought affected households were investigated based on the simulation. Four main scenarios were also created and tested through model simulation. The first set of scenarios was at group level (farmer groups) and included: 1) increase of cultivated area and 2) increase of fertilizer used. These two adaptation strategies were the main responses of farmers as indicated in household survey results. The second group of scenarios was at the commune level and included: 1) increase of percentage of access to irrigation and 2) adjustment of migration rate around the current rate.

The analysis rests on the linkage between the farm typology analysis and model simulation outputs, which can be interpreted or explained through the conceptual model/framework for drought resilience. Recalling the conceptual model for drought resilience, the actual impacts of drought received by a farmer, a group of farmers or a community depend on their capacity of responses, drought characteristics and existing conditions of the study communes. The actual impacts are represented by outcome variables for resilience or vulnerability at household and group levels such as household income, net rice income, percentage of yield losses, dependence on farm and nonfarm income, and degree of yield recovery, and at the community level by community actual harvested area and percentage of drought-affected households. The values of the outcome variables were obtained from model outputs. On the other hand, the existing conditions/attributes of farm household and community were explained through the results of a typology model whose inputs include agricultural input use and farm characteristics. Understanding patterns of agricultural input use and their association with farm characteristics through this typology classification is a core for understanding coping, adaptation, and transformation processes of farmers in response to drought, which can be a guide for explanation of linkages between this typology analysis and model simulation outputs.

4. Results

4.1. Typology analysis

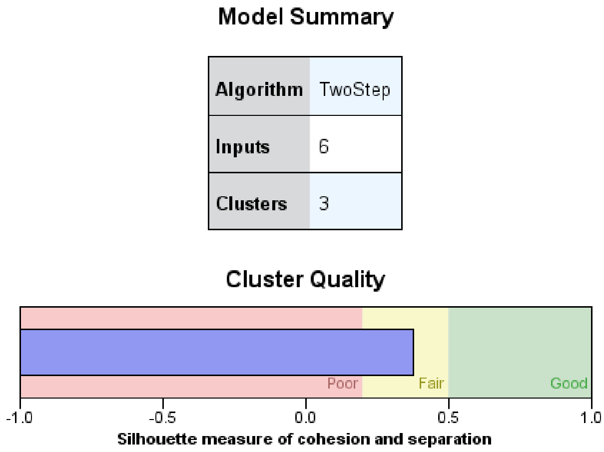

Figure 4: Clustering model for farm typology

The following figure(Figure 5) shows detailed information for each cluster. The input variables (predictors) in the list were arranged from top down by order of importance, and in this case access to irrigation in drought year and varieties used were the two most important factors that differentiate groups of farmers. Other input variables such as those from non-farm dimensions were tested in the model, but they were not significant. From this classification, there were three major groups of farmers, which can be summarized in the following table.

Table 6: Characteristics of farmer groups

Farm Typology	**Characteristics**
Group 1	Least diversification in agriculture, medium-scale farmers without access to irrigation
Group 2	Most diversification in agriculture, large-scale farmers with access to irrigation
Group 3	Fair diversification in agriculture, medium-scale farmers without access to irrigation

Group 1 had the lowest degree of diversification in agriculture, with small land size and without access to irrigation as their paddy fields were far from irrigable water sources. This group of farmers owned just about one to two plots of paddy land (least spatial diversification of paddy fields) and used only late-duration varieties which is the traditional variety that has low yield compared to the medim and short-duration varieties (least varietal diversification).

Group 3 had very similar characteristics to Group 1 except that this group used two or more varieties (varieties diversification). Group 3 constituted almost half of the total households in the community. Last, Group 2 was the most diversifed in agriculture. Farmers in Group 2 owned two or more large paddy plots (spatial diversification of paddy lands), used two or more varieties (varietal diversification) and had access to irrigation as their paddy fields were very close to water sources. This group constitutes around one-third of the total households in the community.

Clusters

Input (Predictor) Importance

1.0 0.8 0.6 0.4 0.2 0.0

Cluster	1	2	3
Size	28.0% (23)	26.8% (22)	45.1% (37)
Inputs	Whether irrigating when facing drought No (100.0%)	Whether irrigating when facing drought Yes (100.0%)	Whether irrigating when facing drought No (100.0%)
	Whether using only late varieties Yes (100.0%)	Whether using only late varieties No (59.1%)	Whether using only late varieties No (100.0%)
	Number of owned paddy plots 1.87	Number of owned paddy plots 2.23	Number of owned paddy plots 1.49
	Owned paddy area under cultivation 2.69	Owned paddy area under cultivation 4.40	Owned paddy area under cultivation 2.96
	Distance of paddy field from water sources 1,376.52	Distance of paddy field from water sources 110.91	Distance of paddy field from water sources 1,765.84
	Fertilizer used per hectare 72.26	Fertilizer used per hectare 99.96	Fertilizer used per hectare 82.33
Evaluation Fields	Paddy yield in 2014 824.02	Paddy yield in 2014 1,264.16	Paddy yield in 2014 1,094.83
	Paddy yield in 2013 1,999.94	Paddy yield in 2013 1,632.02	Paddy yield in 2013 2,181.12
	Percentage of loss due to drought 56.03	Percentage of loss due to drought 28.98	Percentage of loss due to drought 51.46

Figure 5: Farm typology

4.2. Rice yield and uses of agricultural inputs

Figure 6 indicates rice yield fluctuation over years from 2010 to 2050 generated from the model simulation. The oscillation resulted from changes in agricultural inputs over time, especially the changes in water availability for rice cultivation due to rainfall variability. The graph lines peak in normal years and hit their lowest value in drought years. In general, farmers in group 2 do better in drought years, meaning their yield in drought years is higher than the other two groups. This is because this group has access to and irrigates paddy fields when they face drought. However, in normal years, farmers in group 1 and 3 perform better in terms of yield. This is probably because these two groups of farmers use a higher amount of fertilizer per hectare (Figure 7). From in-depth interviews, the reason that farmers in group number 2 use less amount of fertilizer might be because they own a relatively large cultivated area, which requires a large amount of fertilizer. That’s why they tend to use less fertilizer per hectare in average due to financial constraints. The other reason includes soil quality. The more fertile the soil is, the less fertilizer they use.

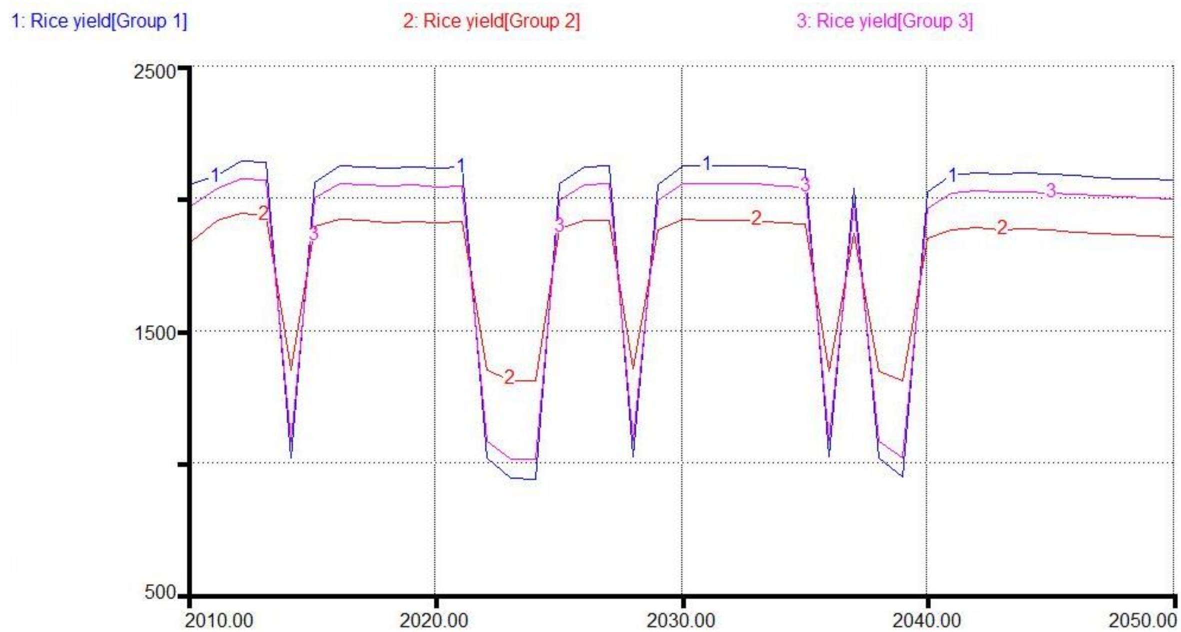

Figure 6: Rice yield for farmers in group 1, 2 and 3

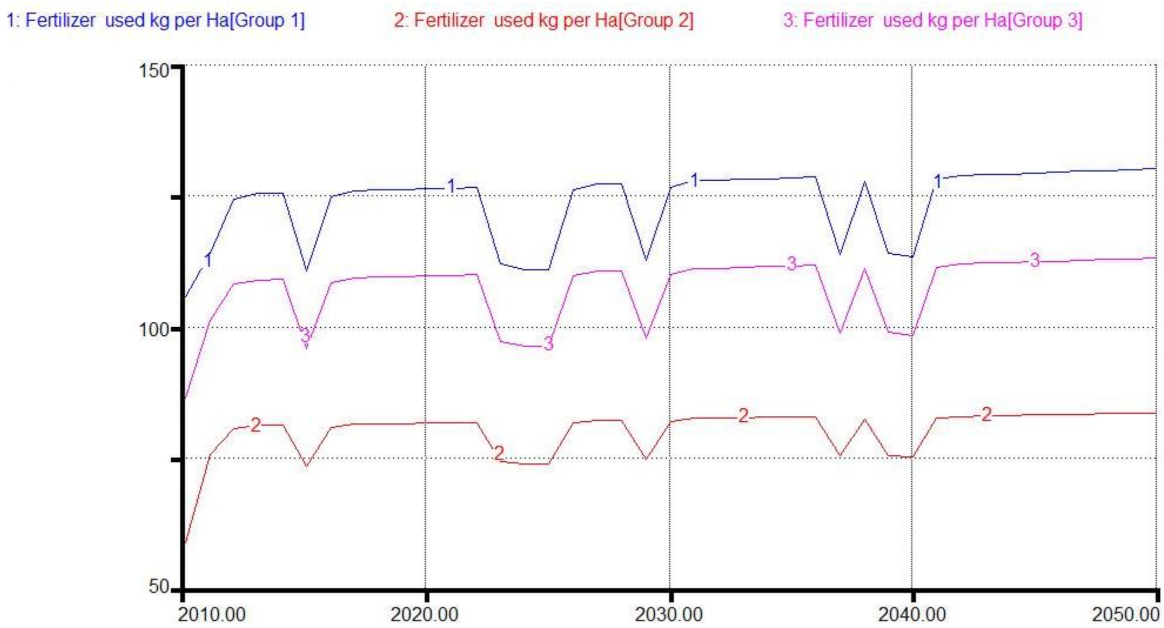

Figure 7: Fertilizers used per hectare

4.3. Agricultural investment and rice profit

Figure 8 below depicts agricultural investment stock over time by farmer groups. It is noticed that investment in agriculture is composed of costs of irrigation, seeds, labor, and fertilizers. From the graph it is clear that in general farmers in group 2 invest more in agriculture over the long-term, followed by farmers in group 3 and group 1. This is because farmers in Group 2 have relatively large area of paddy land, irrigate their rice fields if they face drought, and buy rice seeds in average every two to three years. On the other hand, farmers in group 1 spend less overall even though they generally apply higher amounts of fertilizer per hectare. This is because they have relatively small land, do not irrigate or buy seeds as they use only late-duration varieties which are reserved from the previous cultivating season. Farmers in group 3 have intermediate investment rates.

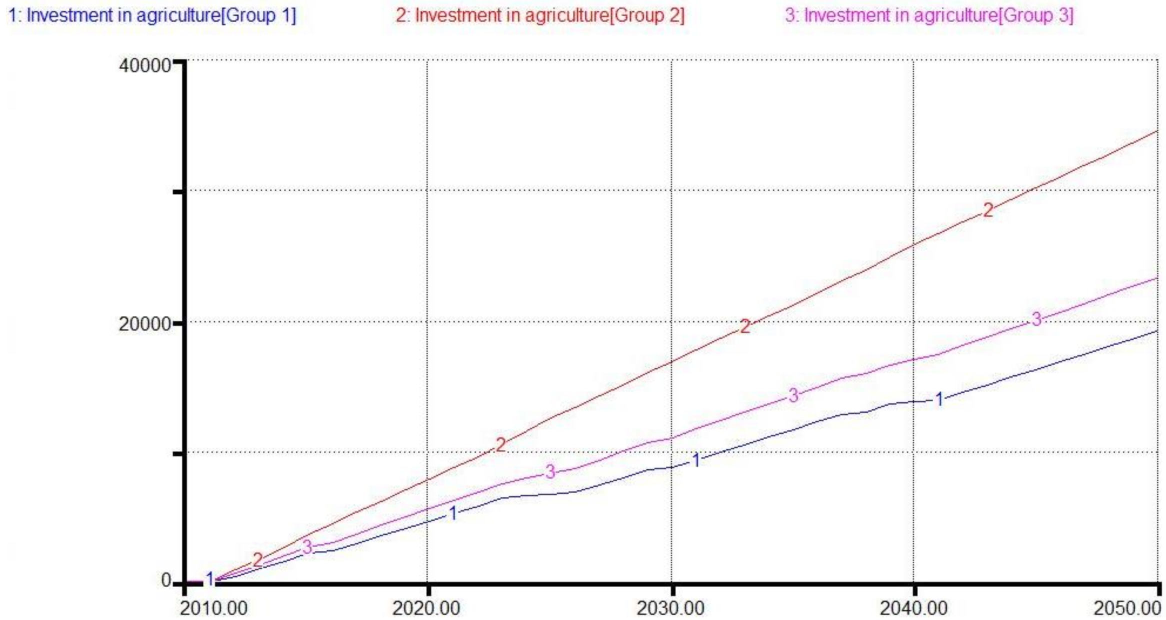

Figure 8: Agricultural investment by groups in USD

Net rice income is equal to the gross rice income minus the production costs (cost of agricultural input). As can be seen from Figure 09, farmers in group 2 have higher net rice income over time, followed by farmers in groups 3 and 1. In addition, farmers in group 2 can maintain profit over time from rice sales even in drought years. On the other hand, farmers in groups 3 and 1 do not make any profit in drought years as net income goes down to zero during these years. There is also relation observed in Figure 08 and 09 between investment in agriculture and rice profit. All in all, it can be inferred from these two figures that, for farmers who have access to irrigation (group 2 in this case), the more they invest in their rice production, the more profit they can make despite the regular occurrence of drought over time. However, if they don't have access to irrigation (group 1 and 3), investment in the agricultural inputs put them at risk of making no profit in the drought years.

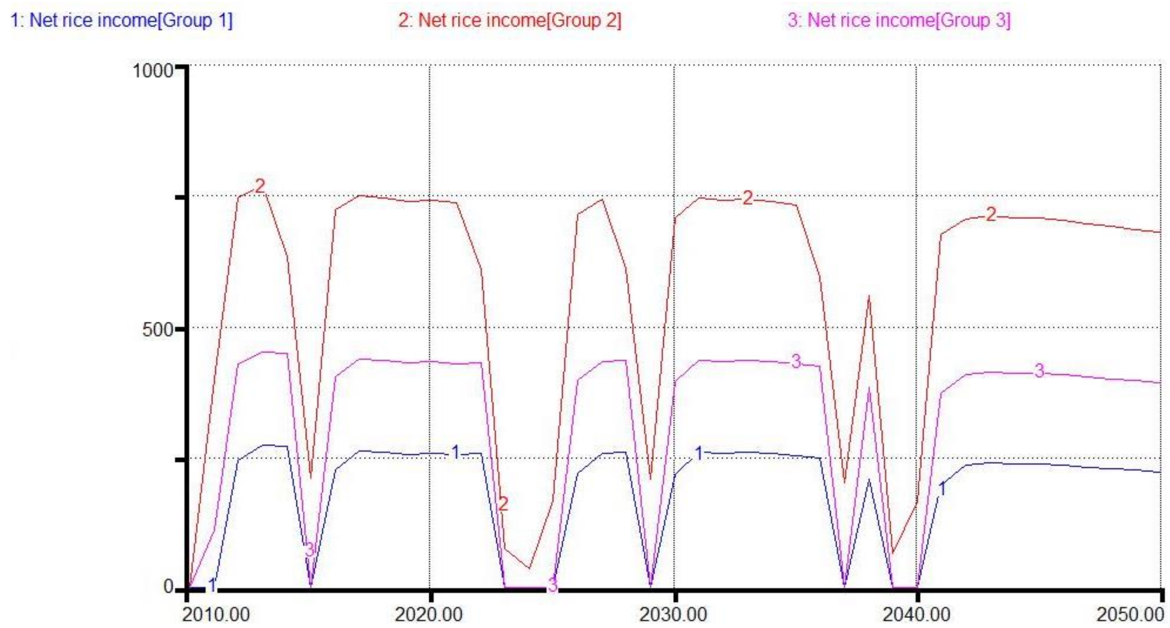

Figure 9: Net rice income in USD

Household income stock in Figure 11 was calculated by the sum of farm income and nonfarm income. Farm income includes rice income, income from other agricultural cultivation (vegetables and crops), while nonfarm income is the sum of local wage, remittance from migration, and other regular nonfarm income. It can be seen in Figure 10 that at the first 10 year of simulation the household income of the three groups of farmers does not differ much but it deviates more after that period. Also, farmers in group 2 are still better off compared to the other two groups. Farmers in group 1 have relatively higher household income compared to those in group 3, despite their lower rice income. This is because they earn more from other nonfarm sources.

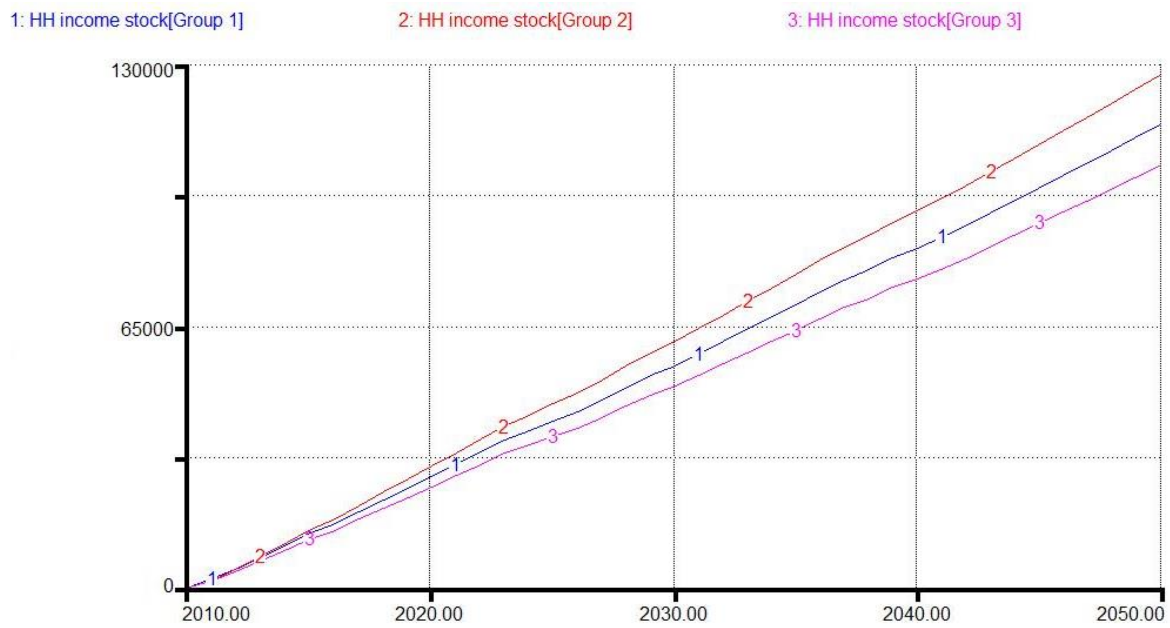

Figure 10: Household income stock

4.4. Dependence on agriculture and other nonfarm activities

Dependence on agricultural and non-agricultural incomes in this case was calculated as the percentage of each individual income source contribution to the total household income. As shown in Figure 11, farmers in group 2 depend more on rice income than the other two groups. For this group, rice income shares almost 50 per cent of the total household income in normal years and approximately 40 per cent in drought years. Farmers in group 1 depend less on rice income. Rice income for this group shares around 30 per cent of total income in normal years, and only 5 per cent in drought years. For farmers in group 3, the share of rice income in normal and drought years fluctuates around 20 to 40 per cent.

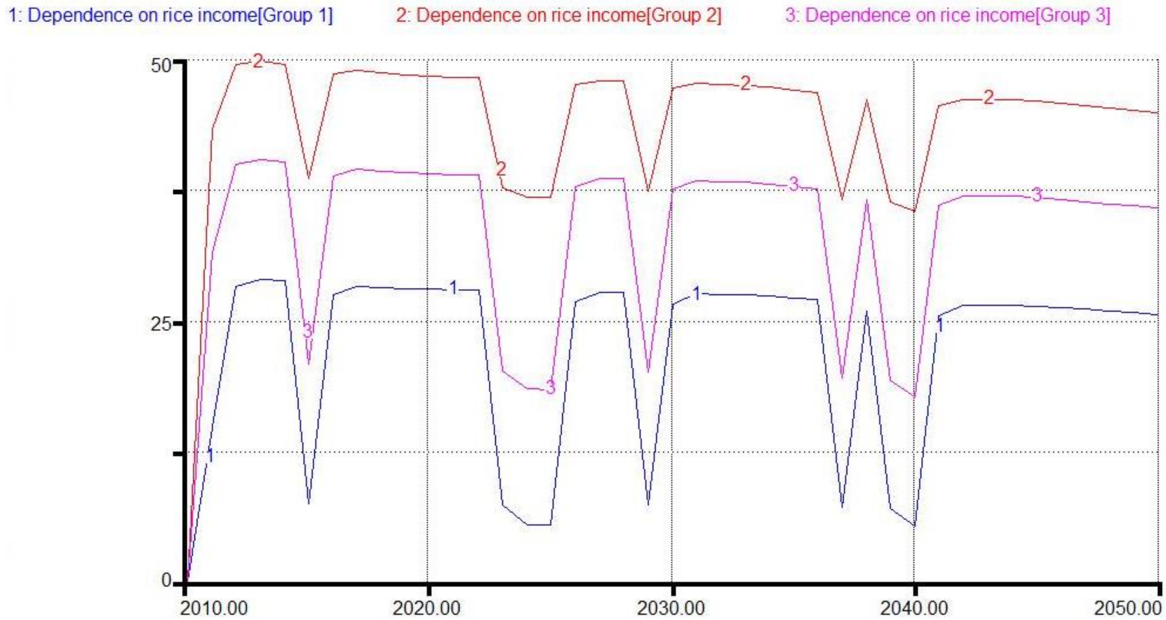

Figure 11: Dependence on rice income

Figure 12 shows that dependence of farmers on remittance from migration does not differ much among the three groups of farmers. The share of remittance from migration to the total household income for the three groups ranges from 1 to 8 per percent and overall, this dependence slightly increases over time.

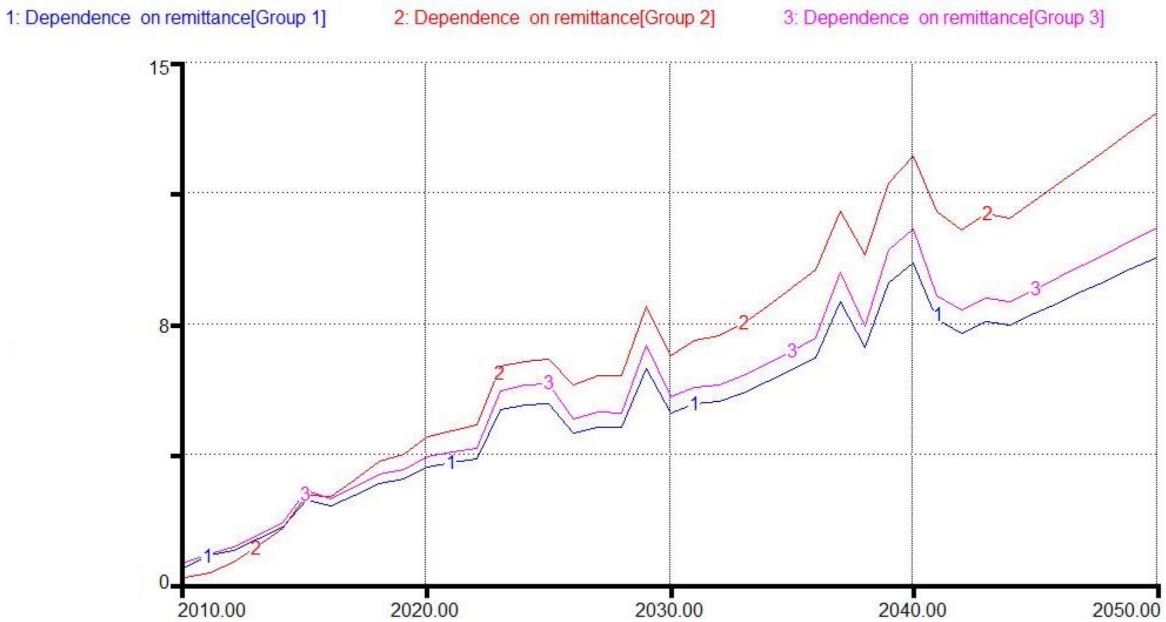

Figure 12: Dependence on remittance from migration

Figure 13 illustrates the dependence of farmers in group one on each income source. It can be seen from this figure that the farmers in this group depend a lot on nonfarm income which contributes up to about 55 to 70 per cent of the total income in normal and drought years. The share of rice income to the total income accounts for around 10 to 25 per cent, while that of other agricultural income shares around 15 per cent only. It is to be noticed that this group of farmers is the least diversified among the three and their household income stock accumulated over time is lower than the other two groups .

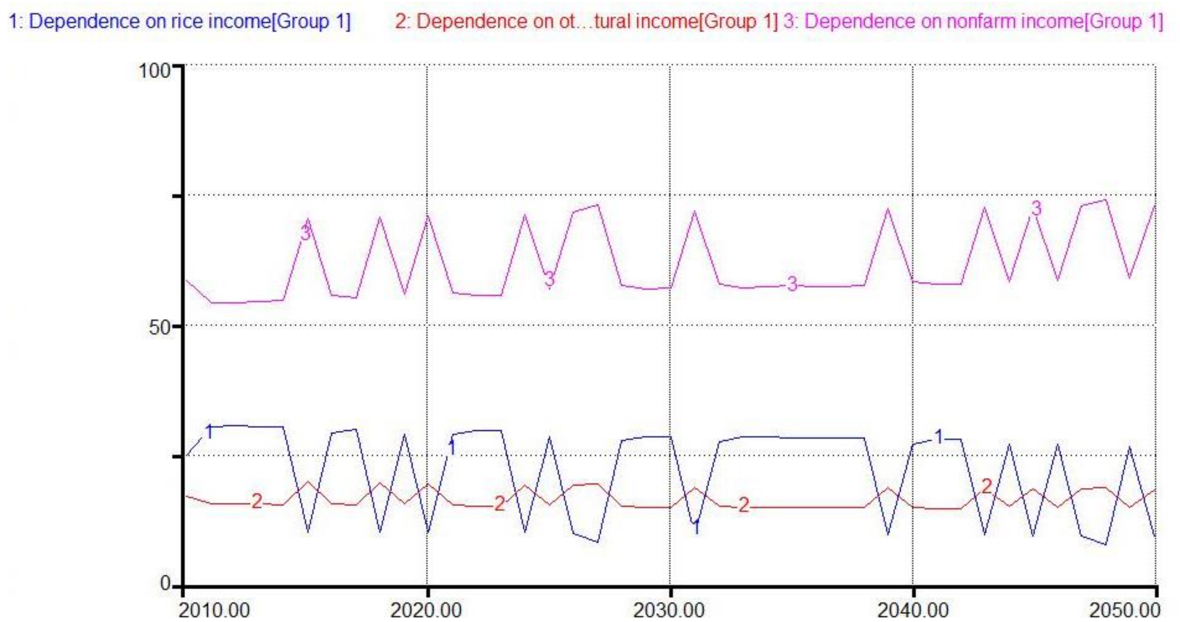

Figure 13: Dependence on different livelihood sources for farmers in group 1

For farmers in group 2 as shown in Figure 14, rice income and nonfarm income are equally important. Both sources of income contribute around 45 per cent of the total household income, while the share from other agricultural income accounts for around 10 per cent. This group of farmers is the most agriculturally diversifed compared to the other two groups, invests in agriculture more, and can still generate rice income during drought years.

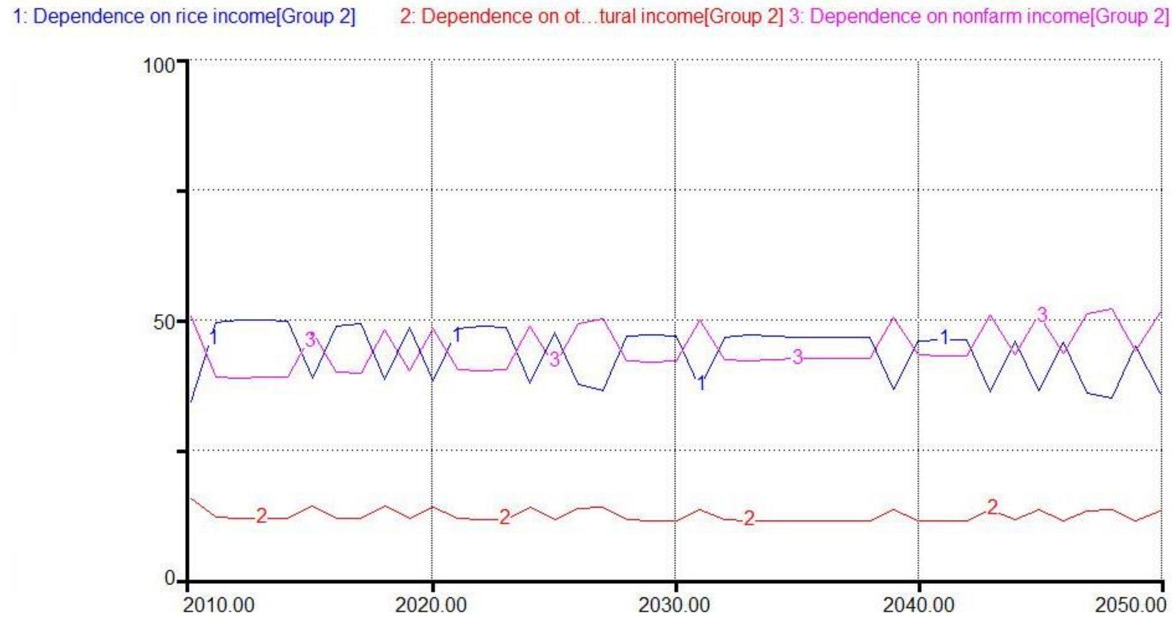

Figure 14: Dependence on different livelihood sources for farmer group two

For farmers in group 3 (Figure 15), the shares of rice income, other agrciltural income, and nonfarm income to total household income do not differ much and range from 25 to 35 per cent. Particularly, this group of farmers weighs the importance of other agricultural income higher than the other two groups. It seems that they do not place relative importance on any single source of income, all sources of income share the same weight.

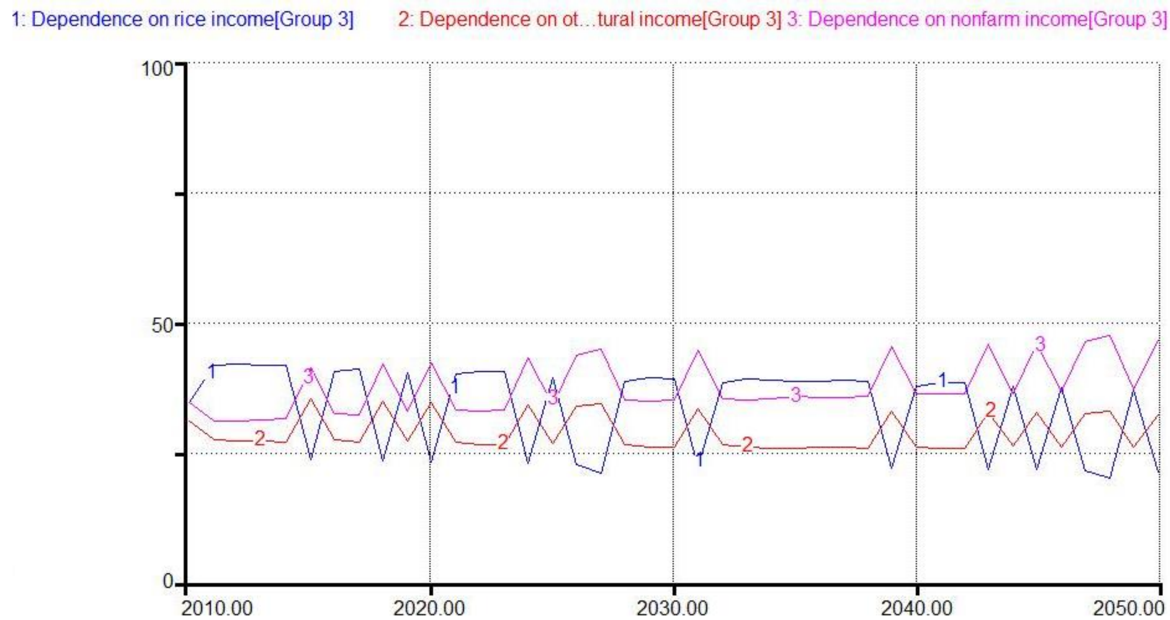

Figure 15: Dependence on different livelihood sources for farmers in group 3

4.5. Recovery from losses due to drought

Figure 16 illustrates to what extent yearly simulated rice yield deviates from the normal rice yield for group 1. In general, the simulated rice yield fluctuates around the normal yield over time. However, during normal years their rice yield goes just above the normal yield, while in drought years, their rice yield goes down far below the normal yield. This means that farmers in group 1 tend to lose more due to drought than they gain in yields over time. They are able to recover from yield loss in drought years, but can go just about the normal yield.

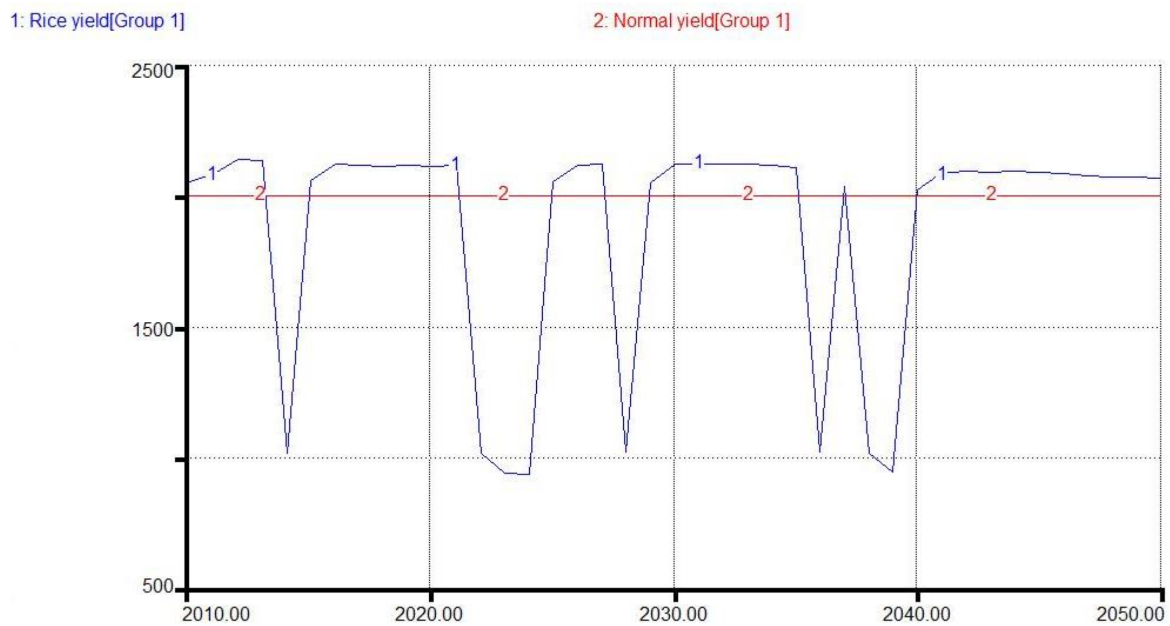

Figure 16: Simulated rice yield and normal rice yield for farmers in group 1

For farmers in group 2, the simulated rice yield also fluctuates around the normal yield (Figure 17). However, this group of farmers has more balance between normal and drought years in terms of yield. It seems that the magnitude of yield losses in drought years does not exceed what they gain in normal years in a long-term perspective. They can recover from drought and make more yield improvement beyond the normal yield. This would be because their normal yield is lower than that of the other groups. Despite this, based on previous results, this group of farmers still makes profit from rice in drought years, while the other two do not.

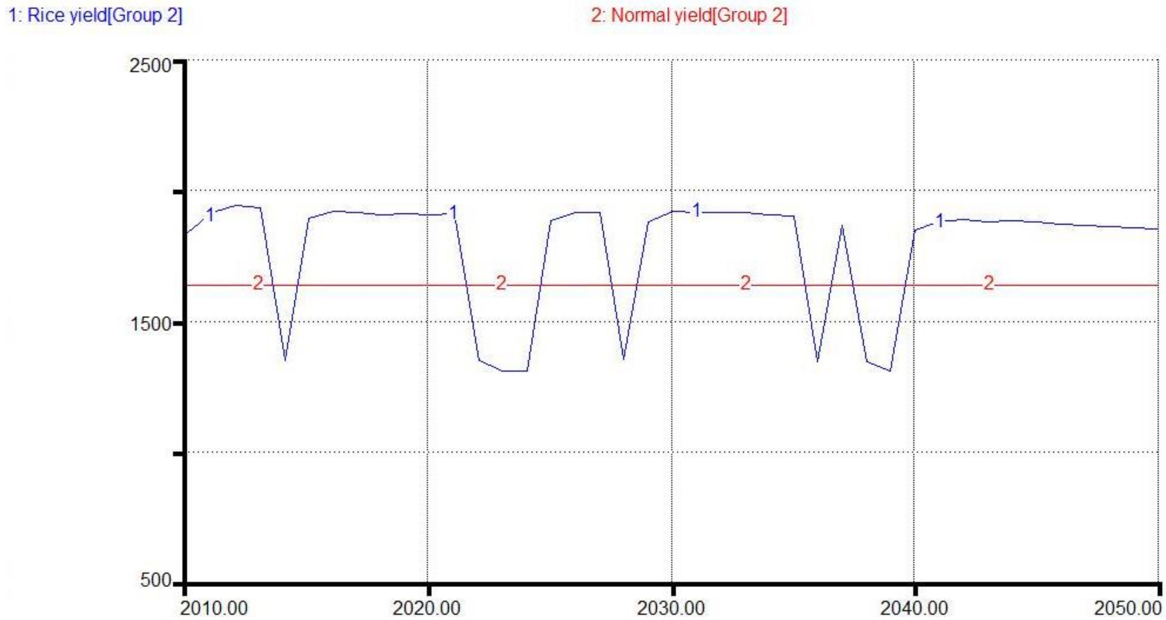

Figure 17: Simulated rice yield and normal rice yield for farmers in group 2

Particularly, over time farmers in group 3 cannot reach the normal yield they first achieved under optimal conditions (Figure 18). This might be because their normal yield is already high and even higher than the other two groups, which makes it difficult to maintain that yield level over time. However, this group performs better than group 1 in drought years in terms of yield based on the above results.

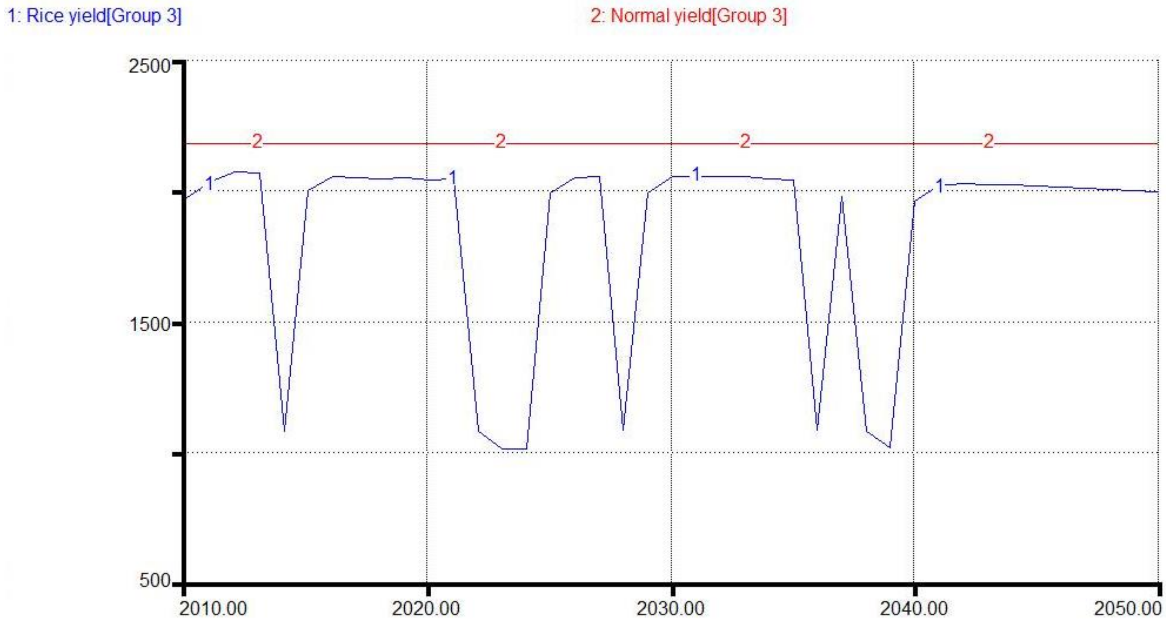

Figure 18: Simulated rice yield and normal rice yield for farmers in group 3

The percentage of yield losses due to drought in this study was calculated by the formula "100*[normal yield-simulated yield]/normal yield". Figure 19 below shows the percentage of yield loss due to drought over time by farmer groups. When the values go below zero, it indicates a yield gain, and the peaks indicate the percentage of yield loss in drought years. The results show that in general all of the three groups lose yield during drought years, but group 2 loses yield much less than the other two.

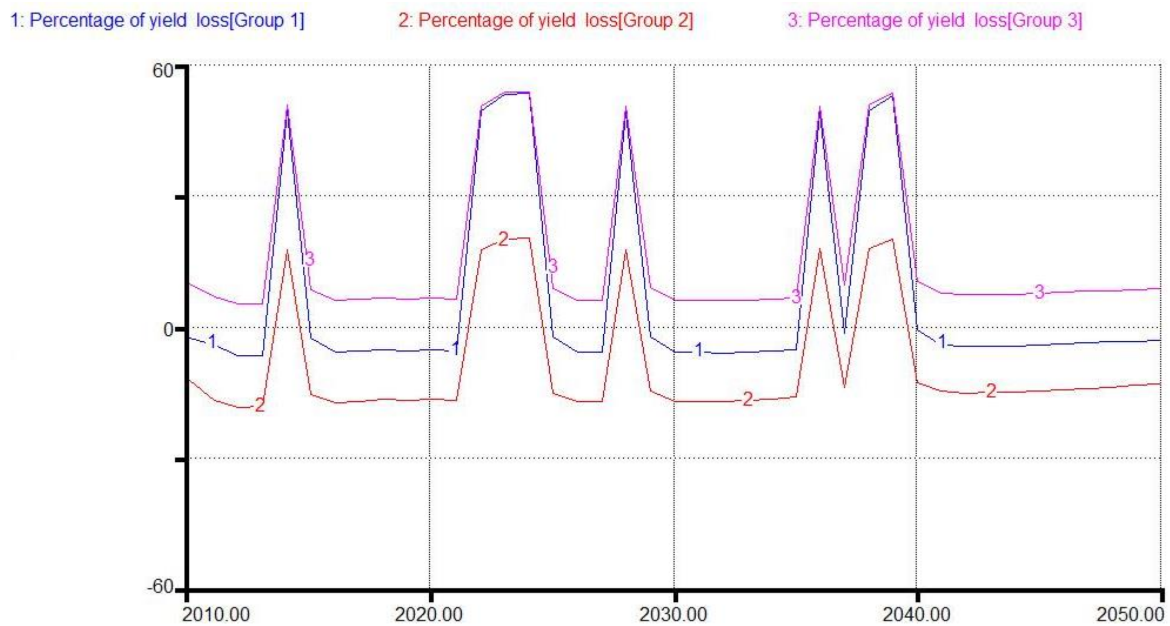

Figure 19: Percentage of yield loss by groups

4.6. Drought impacts at community level

Figure 20 below shows the model simulation results at the commune level. As can be seen from this figure, the actual harvested area decreased and percentage of drought-affected households increased over time. This indicates that the community does not have enough capacity to maintain the available cultivated land over time because the magnitude of drought impacts is larger than what the community can do to moderate the impacts, i.e. to irrigate their paddy lands.

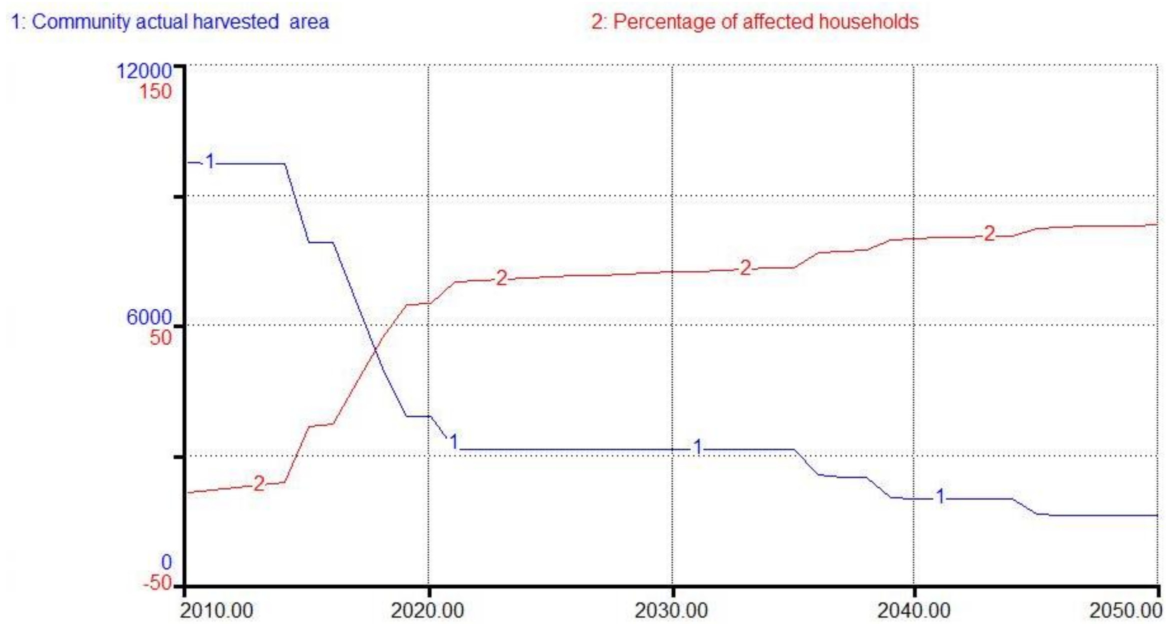

Figure 20: Community actual harvested area and percentage of affected households

4.7. Model Scenario Tests

a) Cultivated Area and Fertilizer Increase Scenarios

For scenario 1, a model test was performed to see how adjustments of agricultural inputs at the household or farm group level have effects on percentage of yield loss and net rice income of farmers in group 1 and group 3 and also to observe how these changes affect the community. This test is to show if the attributes of farmers in group 2 (cultivated area and fertilizer used), who perform well, can be a lesson for groups 1 and 3. First, cultivated areas of farmers in group 1 and 3 were increased to 4.4 ha, similar to the cultivated area of farmers in group 2. The amount of fertilizer per hectare was also increased proportionally, by approximately 20%. The results of these two simulations were compared with those of the initial conditions.

Line N^{o}1 in Figures 21 and 22 represents the baseline condition for group 1 and 3, respectively. Line N^{o}2 shows the simulation in which cultivated area was increased, and Line N^{o}3 the simulation in which both cultivated area and fertilizer were increased for farmer groups 1 and 3. As can be seen from these two figures, there was almost no improvement for either group of farmers in terms of reducing percentage of yield loss due to drought.

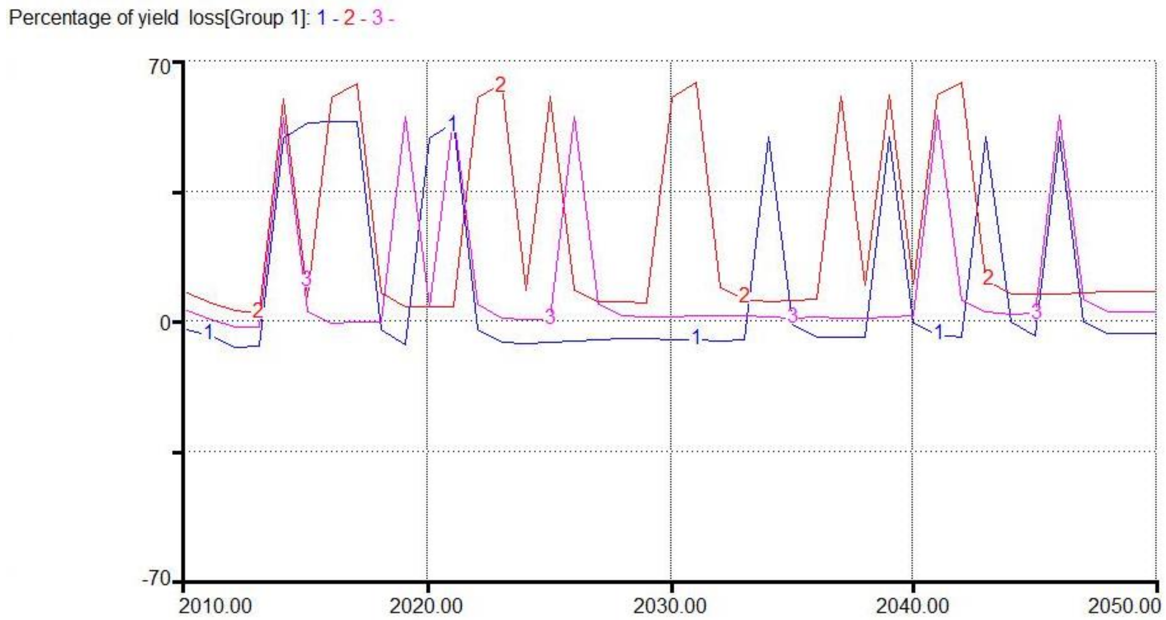

Figure 21: Percentage of yield losses for farmer group 1 under baseline, area increase, and area & fertilizer increase scenarios.

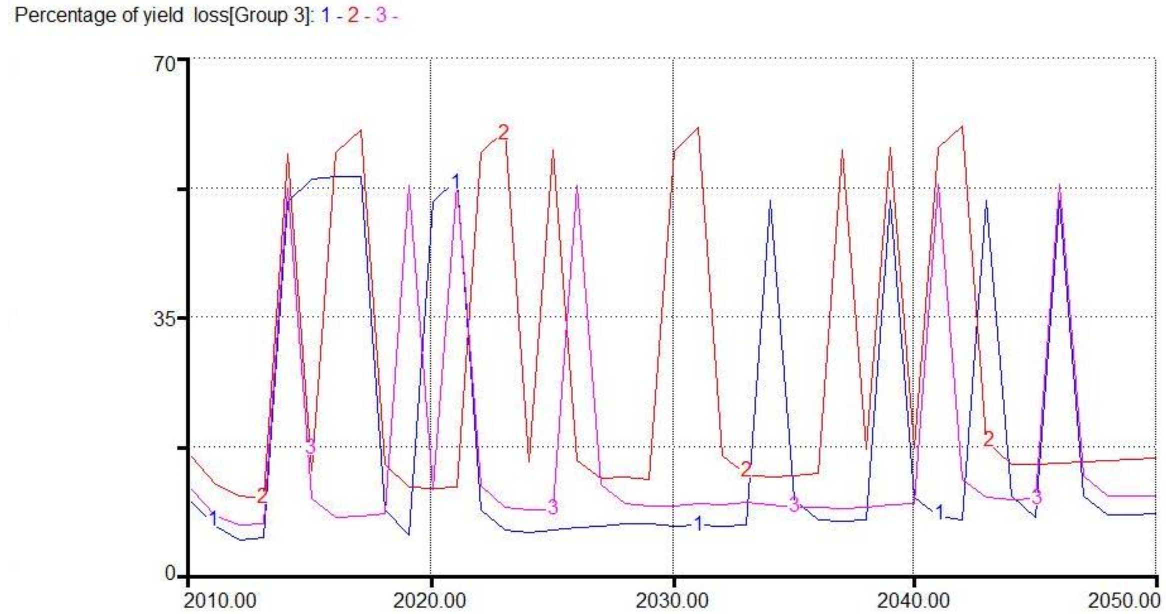

Figure 22: Percentage of yield losses for farmer group 3 under baseline, area increase, and area & fertilizer increase scenarios.

Similarly, Figures 23 and 24 show the effects of the same scenario test on net rice income for farmer groups 1 and 3. Through increasing cultivated area and amount of fertilizer used by these two groups of farmers, they could make more profit from rice cultivation in normal years only. In drought years, they would risk making no profit at all as net rice income goes to zero, but they make more investments in this scenario because of increased land area.

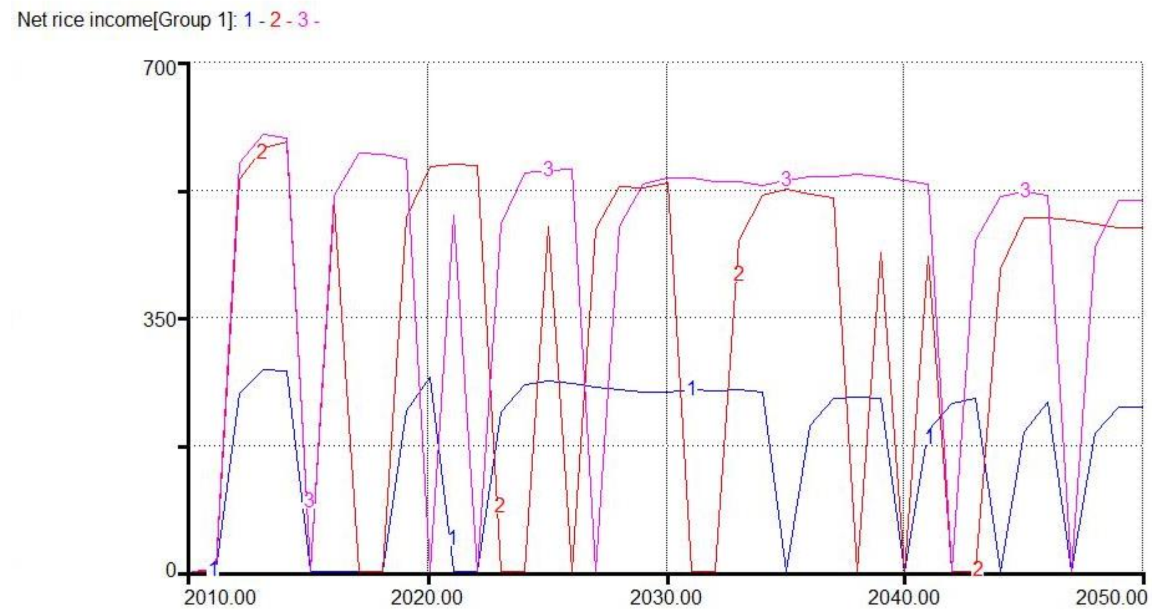

Figure 23: Net rice income for farmer group 1 under baseline, area increase, and area & fertilizer increase scenarios.

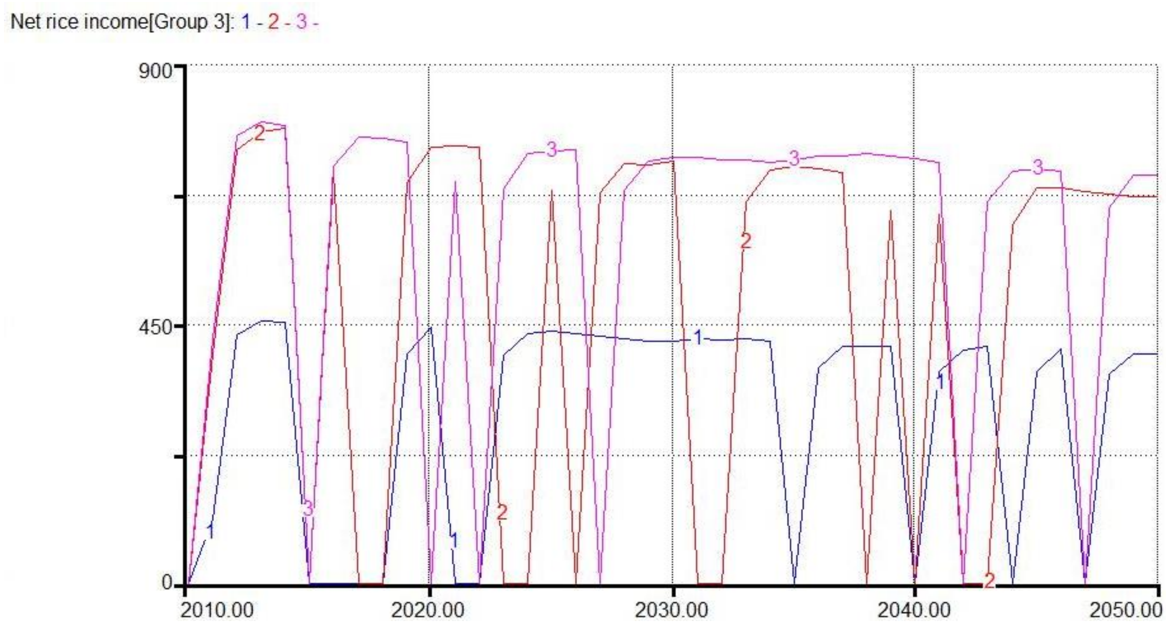

Figure 24: Net rice income for farmer group 3 under baseline, area increase, and area & fertilizer increase scenarios.

Changes at the community level were also observed under these scenarios. Figure 25 and 26 indicate that increase in cultivated area and amount of fertilizer used for groups 1 and 3 have a negative impact on the community, i.e. reducing actual harvested area and increasing number of drought-affected households. This indicates that the characteristics that make farmers in group 2 better off do not necessarily make the other groups better off, and adjustments made at the household/farm group level may have a negative impact on the community. These results are consistent with the above results in terms of magnitude of yield loss and net rice income. Previous results indicate that farmer groups 1 and 3 cannot make profit from rice cultivation in drought years due to high yield loss. So, if these groups of farmers invest in rice cultivation by increasing amount of fertilizer or increasing both fertilizer amount and cultivated area as tested in these scenarios, they may loss more and more when facing drought. To larger extent, if drought frequencies increase, the magnitude of yield loss will be intensified too and as a result, negative impacts of these adjustments can be seen at commune level. In addition, there are also evidences from in-depth interview that support this finding. For instance, there were some farmers that increased rice cultivated land in 2014 by renting the land from others and these farmers reported the huge losses due to severe drought in 2014. On the other hand, some other farmers mentioned that adding fertilizer just after drought period as a way to recover as well as to boost rice growth did not make rice recovered or boosted as they expected. In return, it burnt the rice and made the situation even worse.

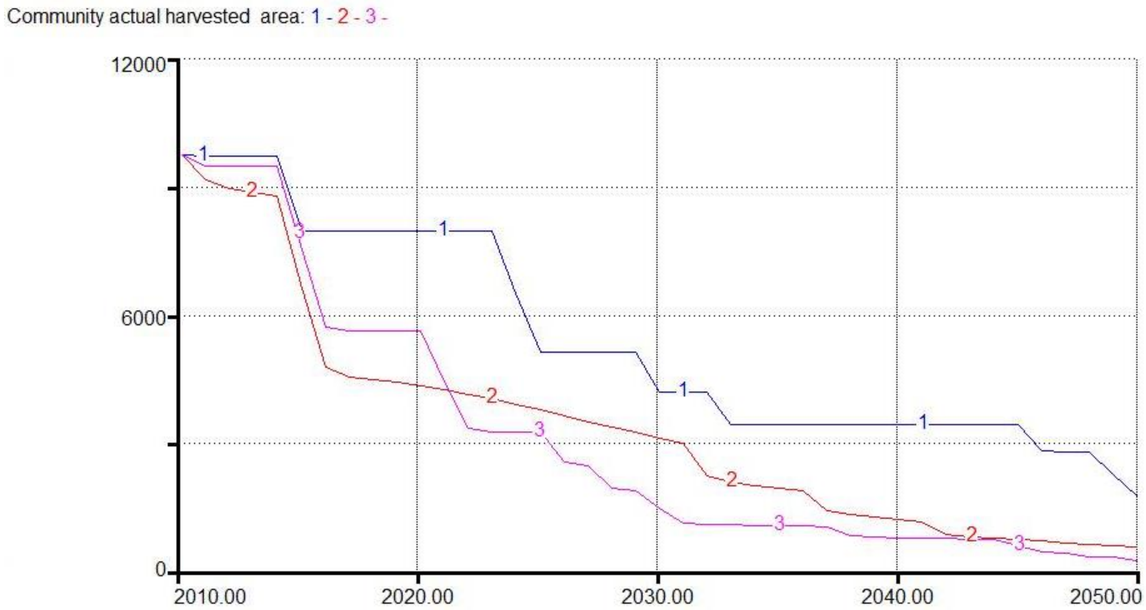

Figure 25: Actual harvested area under baseline, area increase, and area & fertilizer increase scenarios for Groups 1 and 3.

Figure 26: Percentage of drought-affected households under baseline, area increase, and area & fertilizer increase scenarios for Groups 1 and 3.

b) Increase access to irrigation and adjusted migration scenarios

In scenario 2, tests were performed to see how adjustments at the community level affect actual harvested area and percentage of households affected by drought.

- Effect of access to irrigation

Figure 27 below compares community actual harvested area for the current condition of access to irrigation and the condition in which more households would have access to irrigation. Line N^{o} 1 in this figure indicates the community actual harvested area for the current condition in which only 22% have access to irrigation. This line depicts the actual harvested area decreasing over time as drought continues to occur in the future, which indicates that the community is vulnerable to drought. Line N^{o} 2 depicts a scenario in which access to irrigation in the community is increased to 40%. This signifies the threshold level of irrigation which can maintain stability of continuous rice cultivation over time. Thus, if access to irrigation is increased to around 50% or more, it is more likely that the community is better off in the face of drought.

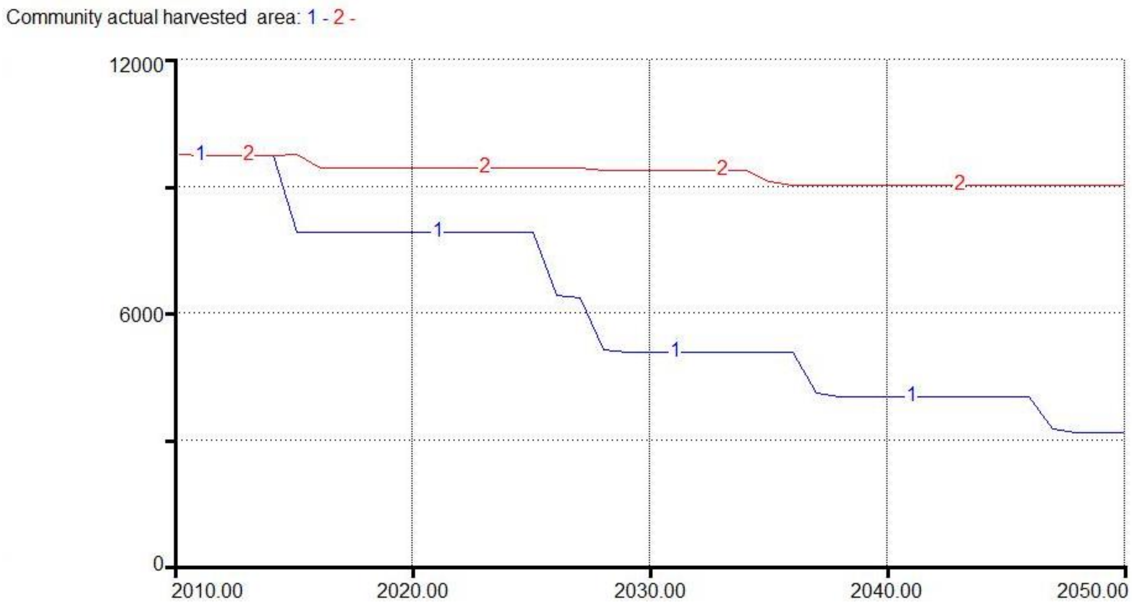

Figure 27: Effect of increase access to irrigation on actual harvested area scenario

Similarly, in Figure 28, line N° 1 indicates the percentage of drought-affected households for the current condition in which only 22% have access to irrigation. Line N° 1 depicts the percentage of drought-affected households increasing over time as drought continues to occur in the future, which indicates the community is vulnerable to drought. If access to irrigation was increased to 40 per cent as indicated in line N° 2, the percentage of drought-affected households increases much more slowly. Thus, if access to irrigation is increased to around 50% or more, it is more likely that the community is more resilient to drought.

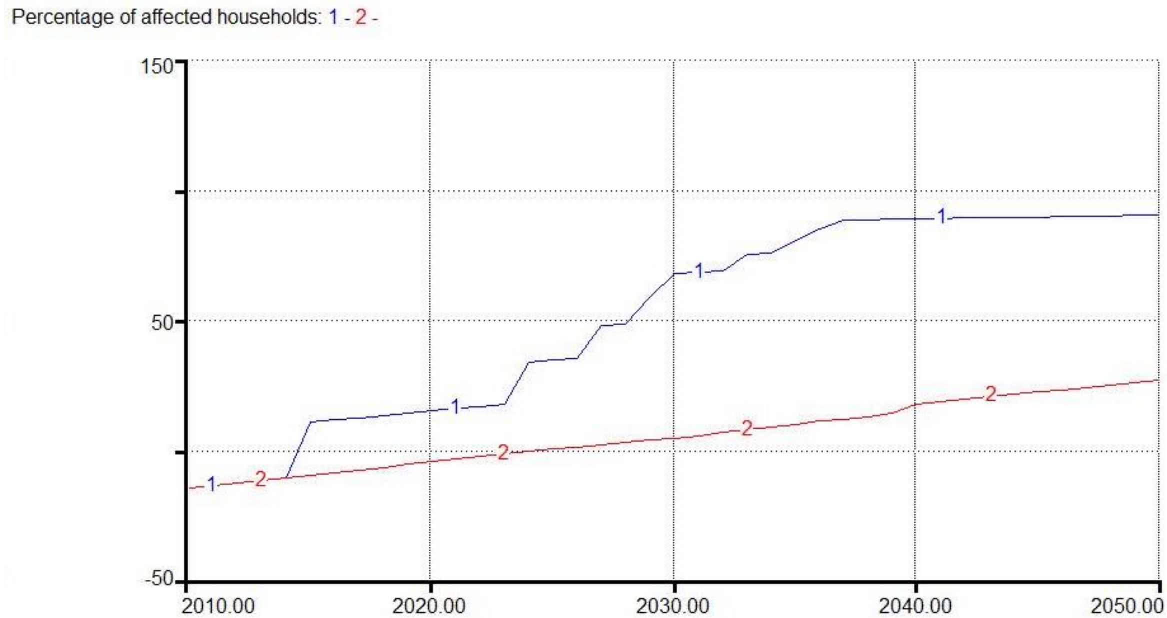

Figure 28: Effect of increase access to irrigation on percentage of affected household scenario

- Effects of migration

For this scenario test, migration rate was adjusted around the current migration rate of 3% (line N° 1) by first increasing to 5% (line N° 2) and then decreasing to 1% (line N° 3). The results show that the more migrations, the less actual harvested area (Figure 28) and the higher the percentage of drought-affected households (Figure 29). This shows the negative impacts of migration on resilience of rice production at community level.

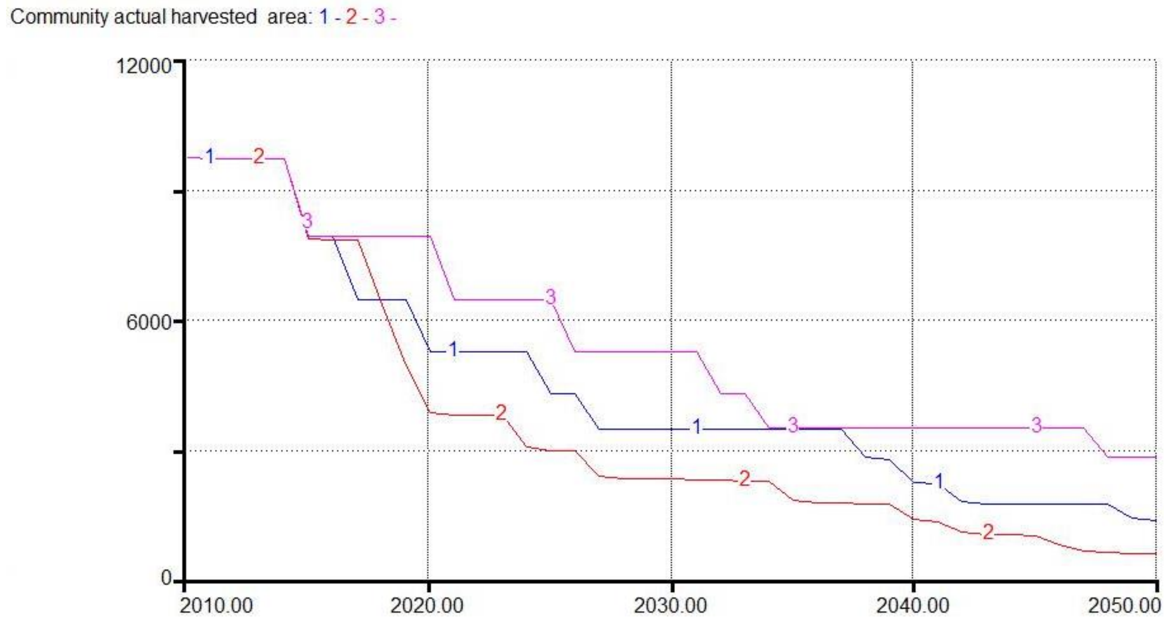

Figure 29: Effect of adjusted migration rate on actual harvested area scenario

Figure 30: Effect of adjusted migration rate on percentage of affected household scenario

5. Discussion

The typology analysis depicts three major groups of farmers who differ from one another by whether they have access to irrigation and their associated degree of diversification in agriculture.

The first group of farmers was the one that had the lowest degree of diversification and no access to irrigation because their paddy fields were located far away from irrigable water sources. They had only one or two paddy plots, used only one type of rice variety (late-duration varieties), and owned relatively small cultivated area. This group constitutes 28% of the population. Looking at their agriculture and livelihood outcomes from model outputs, this group of farmers had the highest yield in normal years as they used more fertilizers than the other two, but in general their total investment in inputs was lower than the other two groups, and as a result their net rice income was relatively low. In addition, they obtained the lowest yield in drought years, which makes them lose much more than the others when facing drought. After facing drought, they could recover their yield to just above their normal yield, but over time it seems they lose yield more frequently than gaining yield. This group of farmers depends a lot on nonfarm income for their livelihood, which accounted for around 60-75% of total income, while rice income and income from other agricultural crops were less important. Thus, it can be inferred from the results of the typology analysis and model simulation that this group of farmers is on the vulnerability/resilience threshold. This group has room for improvement towards resilience by utilizing their resources from nonfarm activities.

The second group of farmers was the most diversified in agriculture and had access to irrigation because their paddy fields were located next to or very close to irrigable water sources. They owned relatively large cultivated area and had both varietal diversification (using two or more varieties) and spatial diversification of paddy lands (having more than two plots). This group makes up around 27% of the population. Considering their agriculture and livelihood outcomes from model outputs, this group of farmers had the lowest yield in normal years as they use less fertilizer than the other two groups, and they own relatively large cultivating area, but they had the highest yield in drought years, which made them lose much less than the first and the third groups in drought years. Clearly, this group benefited from access to irrigation which allowed them to irrigate their paddy fields when facing drought. In general, their total investment in inputs was higher than the other two groups, and as a result their net rice income was relatively high and their accumulative household income was also higher. After facing drought, they could recover their yield to a level well above their normal yield and over time they were gaining more frequently than losing yield. On the other hand, this farmer group depended a lot on both rice income and nonfarm income for their livelihood, which equally made up around 40-50% of the total household income, while income from other agricultural crops was much less significant. Thus, it can be inferred from the results of the typology analysis and model simulation that this group of farmers is resilient to drought.

The third group of farmers was the one that has the average degree of diversification in agriculture and had no access to irrigation because their paddy fields were located far away from irrigable water sources. They had only one paddy plot, owned relatively small cultivated area, but used two or more rice varieties. This group accounted for 45% of the population. Looking at their agriculture and livelihood outcomes from model outputs, this group of farmers had intermediate yield compared to the other two groups, and intermediate amounts of fertilizer used, total investment in inputs, and net rice income. However, in a long-term perspective, their accumulative household income was the lowest among all groups. After facing drought, they could not recover their yield to the level of their normal year and over time they were always losing yield. This farmer group depended equally on nonfarm income, rice income and income from other agricultural crops for their livelihood; each of these sources accounted for around 20-40% of the total household income. Thus, it can be inferred from the results of the typology analysis and model simulation that this group of farmers is vulnerable to drought.

In summary, the third group of farmers is vulnerable to drought, while the first group is on the vulnerability/ resilience threshold. These two groups constitute 73% of the total farm households. Only a small proportion of farmers (27%) is resilient to drought. At the community level of aggregation from the farm group level, model simulation outputs indicate that the community actual harvested area, the area remaining after drought impacts, decreased over time and the percentage of households affected by drought increased over time. Model results from both the farm group level and the community level are consistent, showing that this community is not resilient to drought as the majority of farmers are vulnerable to drought or at the threshold of vulnerability.

Thus, farmers from groups one and three can adapt resilience strategies from farmers in group two. To demonstrate this, scenario tests were performed by modifying agricultural inputs at the group level to see if any changes in drought response would manifest for these two groups and for the whole community. For instance, cultivated area for farmers in group one and three was increased to 4.4 ha, the same as that of group two, the resilient group, and then their amount of fertilizer used per hectare was also increased proportionally (20%). The results show that there was no improvement for either group 1 or group 3 in terms of yield loss reduction or and net rice income improvement. At the community level, these scenarios actually made the situation worse, decreasing actual harvested area and increasing percentage of drought-affected households. This is because the current major adaptation strategies such as increasing fertilizer amount and cultivated area in drought year are not effective enough to cope with drought, but lead to a reverse outcome. These results are also confirmed with answers from some farmers during in-depth interview. Those who cultivated rice on large area of land tend to loss more than those who cultivate rice on smaller area in drought year, given that they don't have access to irrigation.

Another set of scenario tests was also performed to see how changes at the community level can improve resilience. For instance, first, the percentage of households having access to irrigation was increased from the current condition of 22.68% to 40%, and results show that the community actual harvested area and percentage of drought-affected households attained stability over time. This indicates that increasing access to irrigation to about 40% of households can help maintain stability of rice production of the community in the face of drought and increasing to more than this would make the community more resilient to drought. Second, the migration rate was modified around its current rate of 3%, i.e. increased to 5%, and then decreased to 1%. The results indicate that out-migration had negative effects on rice production in a long-term perspective. It decreased community actual harvested area and increased number of drought-affected households.

6. Conclusion

From results and discussions, access to irrigation is the most important source for resilience at both the household and community level. Improving access to irrigation to the threshold level of approximately 40% or more can help maintain stability and continuous development of rice production over time. Another important source of drought resilience is agricultural diversification such as spatial diversification of paddy lands and varietal diversification. The group of farmers that is resilient to drought, i.e. those who can recover from yield loss due to drought, maintain profit from rice cultivation in both normal and drought year and have minimal yield losses due to drought, is associated with this characteristic as seen in the linkage between farm typology and model outputs. On the other hand, nonfarm diversification such as remittance from migration and local wage can be other sources of resilience to drought. However, it is to be noticed that the resilient group is associated with an average degree of dependence on both rice and nonfarm income, denoting that depending too much on nonfarm income might draw resources away from agriculture.

7. Recommendations

From the results of the study, the following recommendations were proposed:

- Improving access to irrigation to approximately 40% can help maintain stability and continuous development of rice production over time. However, more investigation needs to be made so as to identify which group should be provided irrigation access. Institutions are also required to manage the irrigation systems.
- While nonfarm activities are important sources of resilience, improving local employment is a way to strengthen resilience to drought in a long-term perspective because it can minimize the possibility that farmers would move away from agriculture through other nonfarm activities such as out-migration.

8. Limitations of study

For the results of the study, the following limitations need to be considered:

- The relation between yield and agricultural input use estimated through multiple regression is not strong, which may overestimate or underestimate the yield as simulated in the model.
- The relationship between drought and migration was not well understood from the survey responses. Hence, drought-induced migration was not included as a dynamic process in the casual loop diagram.

APPENDICES

AppendiX 1: Multiple regression for yield in 2014 (drought condition) and yield in 2013 (normal condition)

Table 7: Descriptive statistics for agricultural input variables

		Max	Mean	Min	Standard Deviation	Percentile 75	Column N %
Yield in 2014		2400.00	968.93	89.29	588.08	1333.33	
Yield in 2013		4000.00	1889.88	50.00	831.34	2500.00	
Fertilizer per ha in 2014		166.67	74.95	.00	45.16	100.00	
Fertilizer per ha in 2013		166.67	71.03	.00	42.47	100.00	
Ratio of agri. labor to HH size		1.00	.63	.13	.22	.80	
Whether irrigating in 2014	No						77.4%
	Yes						22.6%
Whether using improved varieties 2014	No						14.9%
	Yes						85.1%
Whether using improved varieties 2013	No						20.0%
	Yes						80.0%

a) Regression model for yield in 2014 and agricultural inputs

Table 8: Summary[b] of regression model for yield 2014 and agricultural inputs

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.488[a]	.238	.204	510.38893	1.673

a. Predictors: (Constant), Whether irrigating in 2014, Ratio of agricultural labor to HH size, Whether using improved varieties 2014, Fertilizer per ha in 2014

b. Dependent Variable: Yield in 2014

Table 9: ANOVA[a] of regression model for yield 2014 and agricultural inputs

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7169535.145	4	1792383.786	6.881	.000[b]
	Residual	22923723.894	88	260496.862		
	Total	30093259.039	92			

a. Dependent Variable: Yield in 2014
b. Predictors: (Constant), Whether irrigating in 2014, Ratio of agricultural labor to HH size, Whether using improved varieties 2014, Fertilizer per ha in 2014

Table 10: Coefficients[a] of regression model for yield 2014 and agricultural inputs

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
	B	Std. Error	Beta			Zero-order	Partial	Part
(Constant)	137.899	223.219		.618	.538			
Fertilizer per ha in 2014	3.791	1.209	.301	3.136	.002	.355	.317	.292
Ratio of agricultural labor to HH size	342.466	237.436	.135	1.442	.153	.146	.152	.134
Whether using improved varieties 2014	292.693	150.037	.184	1.951	.054	.215	.204	.182
Whether irrigating in 2014	298.679	132.479	.220	2.255	.027	.329	.234	.210

b) Regression for yield in 2013 and agricultural inputs

Table 11: Summary[b] of regression model for yield 2013 and agricultural inputs

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.341[a]	.116	.064	774.08397	2.137

a. Predictors: (Constant), Whether irrigating in 2014, Ratio of agricultural labor to HH size, Whether using improved varieties 2013, Fertilizer per ha in 2013
b. Dependent Variable: Yield in 2013

Table 12: ANOVA[a] of regression model for yield 2013 and agricultural inputs

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5282530.631	4	1320632.658	2.204	.078[b]
	Residual	40146801.408	67	599205.991		
	Total	45429332.039	71			

a. Dependent Variable: Yield in 2013

b. Predictors: (Constant), Whether using improved varieties 2013, Whether irrigating 2014, Ratio of agricultural labor to HH size, Fertilizer per ha in 2013

Table 13: Coefficients[a] of regression model for yield 2013 and agricultural inputs

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
	B	Std. Error	Beta			Zero-order	Partial	Part
(Constant)	1328.995	365.586		3.635	.001			
Fertilizer per ha in 2013	4.822	2.249	.259	2.144	.036	.193	.253	.246
Whether irrigating in 2014	-533.545	231.718	-.279	-2.303	.024	-.183	-.271	-.264
Ratio agricultural labor to HH size	442.605	397.981	.131	1.112	.270	.117	.135	.128
Whether using improved varieties 2014	11.781	247.810	.006	.048	.962	-.004	.006	.005

a. Dependent Variable: Yield in 2013

AppendiX 2: Regression model for household income and fertilizer used

Table 14: Descriptive statistics for household income and total fertilizer in 2014

	N	Minimum	Maximum	Mean	Std. Deviation
HH income	94	125.00	16631.00	2649.9176	3104.03410
Total fertilizer in 2014	99	.00	1799.00	311.4343	277.64252
Valid N (listwise)	94				

Table 15: Summary of regression model for household income and fertilizer used

R	R Square	Adjusted R Square	Std. Error of the Estimate
.511	.261	.252	168.116

The independent variable is HH income.

Table 16: ANOVA of regression model for household income and fertilizer used

	Sum of Squares	df	Mean Square	F	Sig.
Regression	817867.834	1	817867.834	28.938	.000
Residual	2317555.976	82	28262.878		
Total	3135423.810	83			

The independent variable is HH income.

Table 17: Coefficient of regression model for household income and fertilizer used

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
HH income	.060	.011	.511	5.379	.000
(Constant)	159.951	28.310		5.650	.000

AppendiX 3: Model equations

Rice yield

if Whether_drought_year=1 then (316.045+5.103*Amount_of_fertilizer_used_Kg_per_Ha+412.571*Whether_irrigating_in_drought_year+150.715*Whether_use_improved_varieties+120.952*Ratio_of_agricultural_labors_to_HH_size) else (1328.995+4.822*Amount_of_fertilizer_used_Kg_per_Ha-533.545*Whether_irrigating_in_drought_year+11.781*Whether_use_improved_varieties+442.605*Ratio_of_agricultural_labors_to_HH_size)

Whether_drought_year

if Time_series__of_rainfall<1074.3 then 1 else 0

Amount_of_fertilizer_used_Kg_per_Ha

Total_fertilizer__used/Cultivated__area

Whether_irrigating_in_drought_year

if Whether_drought_year=1 then 1 else 0

Whether_use_improved_varieties

[1=yes; 0=no]

Ratio_of_agricultural_labors_to_HH_size

(Number_of__agricultural_labor/Number__of_HHs)/HH_size

Rice harvest

Rice_yield*Cultivated__area

Rice consumption

HH_size*Rice_consumption_per_capita/Rice_to_rice_milled__conversion_factor

Rice to rice milled conversion factor: 0.64

Rice consumption per capita: 150 [kg]

HH size: 5.5

Rice sale

Rice_stock-Rice__consumption-Rice_seeds

Rice seeds

if Whether_use_improved_varieties=0 then Rice_seeds_used__kg_per_Ha*Cultivated__area else 0

Investment in agriculture

Total_production_cost_per_ha*Cultivated__area

Rice income

Rice_sale*Price__USD_per_kg

Price USD per kg: 900/4000 [USD]

Investment in agriculture

Total_production_cost_per_ha*Cultivated__area

Cultivated area: (4.59, 3.48, 3.88) [m^2]

Total production cost per ha

(Cost_of_labor_per_ha+Cost_of_fertilizer_per_Ha+Cost_of_seeds_per_Ha+Cost_of_traction_means_per_ha+Cost_of_irrigation_per_ha)

Cost of fertilizer per ha

Amount_of_fertilizer_used_Kg_per_Ha*Cost_of_fertilizer_per_Kg

Cost of fertilizer per kg: 0.75 [USD]

Cost of seeds per ha

if Whether_use_improved_varieties=0 then 0 else Cost_of_seeds_per_Kg*Amount_of_seeds__Kg_per_Ha/3

Amount of seeds per ha: 100 [kg]

Cost of seeds per kg: 0.375 [USD]

Cost of irrigation per ha

if Whether_drought_year=0 then 0 else if Whether_irrigating_in_drought_year=0 then 0 else 30

Cost of labor per ha: 288000/4000 [USD]

Cost of traction means per ha: 50 [USD]

HH income

Farm_income + Nonfarm_income

Farm income

Other_agricultural_income + Rice_income

Other agricultural income: (1109.43, 395.05, 362.17) [USD]

Nonfarm income

Other_nonfarm__income+Local_wage+Remittance__from_migration

Other nonfarm income: (1121.17, 688.62, 297.29) [USD]

Local wage: (218.7, 119.71, 232.71) [USD]

Remittance from migration:

Remittance_per_capita*Avg_number_of_migrants_per_HH

Avg number of migrants per HH

Out_migrant_stock/Number__of_HHs

Remittance per capita

Community_remittance/Out_migrants

Community remittance: 23933 [USD]

Out migrants stock: 216

Out migrants

Migration_rate*Number_of__agricultural_labor

Migration rate: 1.30/100

Number of agricultural labor: 6984

Number of HHs

Population/HH_size

Population: 14349

People becoming active

Population*Rate_of_becoming__active_labor

Rate of becoming active

RANDOM(-3.69/100,3.53/100)

Migration: Out migrants

Death

Population*Death_rate

Death rate: 7.78/1000

Birth

Population*Birth_rate

Birth rate: 30/1000

Community drought affected area

(1/100)*Community_actual_harvested__area*(Percent_loss_per_year[Group_1]*30.7/100+Percent_loss_per_year[Group_2]*28/100+Percent_loss_per_year[Group_3]*41.3/100)

Community actual harvested area: 4667+5062 [m^2]

Percent loss per year:

100*(Normal_yield-Rice_yield)/Normal_yield

Normal yield: (2045.39, 2135.22, 1895.45)

Community irrigated area

Community_actual_harvested__area*Percentage_of_HHs_irrigating_when_drought

Percentage of HHs irrigating when drought:

if Whether_drought_year=1 then 22.68/100 else 0

Number of HHs affected by drought

Community_drought__affected_area/(Cultivated__area[Group_1]*30.7/100+Cultivated__area[Group_2]*28/100+Cultivated__area[Group_3]*41.3/100)

Number of HHs irrigating when drought

Community_irrigated_area/(Cultivated__area[Group_1]*30.7/100+Cultivated__area[Group_2]*28/100+Cultivated__area[Group_3]*41.3/100)

Percentage of affected HHs

if 100-100*Total_number_of_none_affected_HHs/Number__of_HHs<0 then 0 else 100-100*Total_number_of_none_affected_HHs/Number__of_HHs

Total number of none affected HHs: 2998

Time series of rainfall

If Time <2015 then Historical__rainfall else Projected__rainfall

Projected rainfall

RANDOM(907.1,1707.4,0.1)

Historical rainfall

TIME

Appendix 4

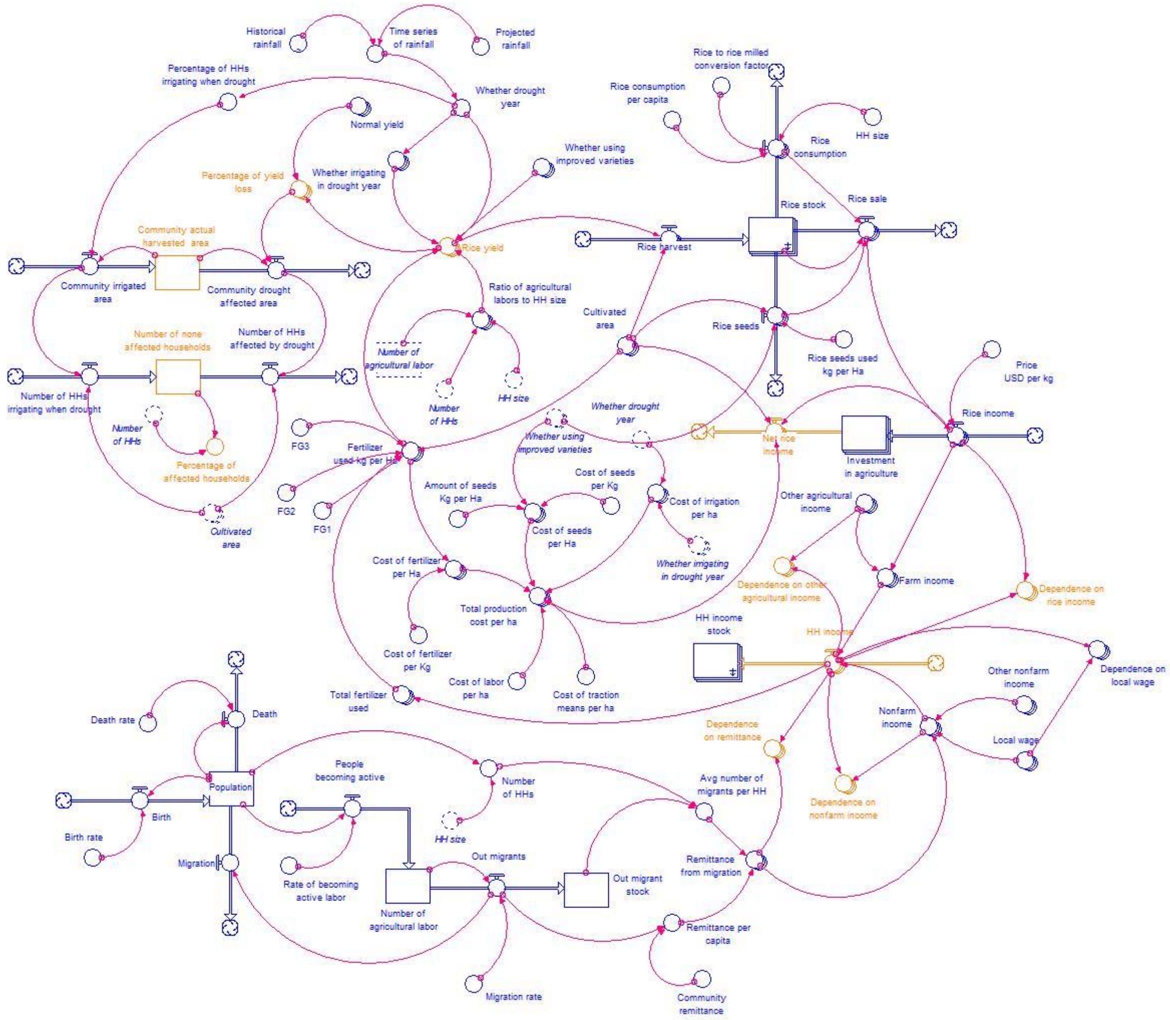

Figure 31: Model structure

BIBLIOGRAPHY

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ADB. (2014). Key Indicators for Asia and the Pacific 2014. Retrieved from http://www.adb.org/sites/default/files/publication/43030/cam.pdf

Adger, W. N. (2000). Social and ecological resilience: are they related? *Progress in Human Geography*, *24*(3), 347–364. doi:10.1191/030913200701540465

Adger, W. N., Brown, K., Nelson, D. R., Berkes, F., Eakin, H., Folke, C., … Tompkins, E. L. (2011). Resilience implications of policy responses to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(5), 757–766. doi:10.1002/wcc.133

Adger, W. N., Kelly, P. M., Winkels, A., Huy, L. Q., & Locke, C. (2002). Migration, Remittances, Livelihood Trajectories, and Social Resilience. *AMBIO: A Journal of the Human Environment*, *31*(4), 358. doi:10.1639/0044-7447(2002)031[0358:MRLTAS]2.0.CO;2

Béné, C., Newsham, A., & Davies, M. (2013, March 1). Making the most of resilience. *IDS In Focus Policy Briefings*. Institute of development studies. Retrieved from http://eprints.soas.ac.uk/18033/1/IF32.pdf

Béné, C., Wood, R. G., Newsham, A., & Davies, M. (2012). Resilience: New Utopia or New Tyranny? Reflection about the Potentials and Limits of the Concept of Resilience in Relation to Vulnerability Reduction Programmes. *IDS Working Papers*, *2012*(405), 1–61. doi:10.1111/j.2040-0209.2012.00405.x

Bennett, E. M., Cumming, G. S., & Peterson, G. D. (2005). A Systems Model Approach to Determining Resilience Surrogates for Case Studies. *Ecosystems*, *8*(8), 945–957. doi:10.1007/s10021-005-0141-3

Berkes, F. (2007). Understanding uncertainty and reducing vulnerability: lessons from resilience thinking. *Natural Hazards*, *41*(2), 283–295. doi:10.1007/s11069-006-9036-7

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From Metaphor to Measurement: Resilience of What to What? *Ecosystems*, *4*(8), 765–781. doi:10.1007/s10021-001-0045-9

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, *18*(4), 598–606. doi:10.1016/j.gloenvcha.2008.07.013

EM-DAT. (2014). EM-DAT: The OFDA/CRED International Disaster Database. Brussels: Université catholique de Louvain. Retrieved from http://www.emdat.be/result-country-profile

Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, *16*(3), 253–267. doi:10.1016/j.gloenvcha.2006.04.002

Frankenberger, T., Mueller, M., Spangler, T., & Alexander, S. (2013). Community Resilience: Conceptual Framework and Measurement Feed the Future Learning Agenda. *Rockville, Md.: Westat*.

Holling, C. S. (1973). RESILIENCE AND STABILITY OF ECOLOGICAL SYSTEMS. *Annual Review of Ecology and Systematics*, *4*, 1–23.

IPCC, 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., … Myeong, S. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (pp. 25–64). Cambridge: Cambridge University Press. doi:10.1017/CBO9781139177245

Mcsweeney, C., New, M., & Lizcano, G. (2008). *UNDP Climate Change Country Profiles Cambodia*.

National Committee for Sub-National Democratic Development. (2010). Commune Database Online. Retrieved December 29, 2014, from http://db.ncdd.gov.kh/cdbonline/home/index.castle

Pandey, S. (2007). Economic costs of drought and rice farmers' coping mechanisms. *International Rice Research Notes*. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=qr2007000068

Ros, B., Nang, P., & Chhim, C. (2011). *Agricultural Development and Climate Change : The Case of Cambodia*.

Scoones, I. (1998). Sustainable Rural Livelihoods: A Framework for Analysis. IDS.

Thomas, T. S., Ponlok, T., Bansok, R., Lopez, T. De, Chiang, C., Phirun, N., & Chhun, C. (2013). *Cambodian Agriculture: Adaptation to Climate Change Impact*. Retrieved from http://www.ifpri.org/publication/cambodian-agriculture

USAID. (2012). *Building Resilience to Recurrent Crisis: USAID POLICY AND PROGRAM GUIDANCE*. Retrieved from http://www.usaid.gov/sites/default/files/documents/1866/Policy %26 Program Guidance - Building Resilience to Recurrent Crisis_Dec 2012.pdf

USDA-FAS. (2010). CAMBODIA: Future Growth Rate of Rice Production Uncertain. Retrieved January 2, 2015, from http://www.pecad.fas.usda.gov/highlights/2010/01/cambodia/

Walker1a, B., & Carpenter, S. (2002). Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation* …. Retrieved from http://ovc.uoguelph.ca/personal/ecosys/ecocourse/Walkeretal.pdf

Wilhite, D. A., Svoboda, M. D., & Hayes, M. J. (2007). Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness. *Water Resources Management*, *21*(5), 763–774. doi:10.1007/s11269-006-9076-5

Yu, B., & Fan, S. (2009). *Rice Production Responses in Cambodia*.

Yusuf, A. A., & Francisco, H. (2009). *Climate Change Vulnerability Mapping for Southeast Asia*.