Responding to Rainfall Variability at the Farm Level: Sustainable Water Management in River Communities of Champhone District, Savannakhet Province, Lao PDR

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ABSTRACT

A large majority of the rural population of Lao PDR remains dependent on agriculture for their livelihood and food security, and access to and management of both irrigated and rain-fed water sources is critical. Crop choices and planting calendars follow a monsoonal (dry season/wet season) weather system, and are very vulnerable to deficits of rainfall in the dry season and oversupply in the wet season. The rainfall patterns that farmers depend on are being increasingly disrupted by climate change, requiring new coping strategies. Climate change projections show that flood vulnerable areas like Savannakhet province might face worse problems in the future. The lack of solutions to both flood and drought in the central and southern part of Laos where Savannakhet province is located can affect food security and agricultural development. This study examines how households are being affected by flooding and drought in Champhone district and coping strategies currently used by farmers. The study focuses on 3 low-elevation villages located along the banks of the Xe Champhone River, the main water resource for farmers in the district. A mixed-method research design was conducted combining key informant interviews at different scales of government and with local people, and household surveys with a total of 157 household heads to assess vulnerability to variable rainfall during the rainy season and dry season. Overall, the findings show that low income, lack of non-rice livelihoods with better income potential, low level of education for off-farm employment opportunities, and weak services and infrastructure are all factors in the vulnerability of communities to flooding, extreme rainfall events and drought.

The main contribution of the research design has been to combine study of climatic conditions with analysis of social data and institutional capacity at different scales, with the aim of supporting community members to identify ways to protect their water supply against climate variability through storage methods, and also to understand rainfall variability and how to adapt crop types. Flood vulnerability was assessed by calculating the rainfall variation to determine runoff of the water balance during rainy season and dry season. The findings show that the minimum runoff is very low in dry season ($Q = 2.5$ m^3/sec), while the maximum runoff is high in rainy season (Q = 274 m^3/sec). Although the maximum and minimum flows are understood to be the result of the monsoonal weather system, the very high variation highlights the sensitivity of local communities to flooding and drought. Meanwhile, the hydrological analysis estimated the intensity of rainfall in 50, 100, 200 and 400 year return periods and runoff of surface water in different seasons using rainfall data from 1995 to 2015, showing increasing variability and intensity in future. Combining this with social data showed that flood and drought sensitivity is heightened by low adaptive capacity to respond to climate change. With severe flooding, villagers would not have enough food as early as 2034 because they cannot grow rice during the dry season due to lack of irrigation. SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis identified irrigation ponds and reservoirs as a suitable water management method to maintain rice sufficiency in the study areas, based on local socioeconomic capacity and projected population growth. Strengthening the climate change resilience of the communities in sustainable water management requires significant planning capacity at community, district, provincial and national scales. The findings of the study are applied to regional recommendations for further consideration in response to similar climatic conditions.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AfDB	African Development Bank
AR4	Forth Assessment Report
AR5	Fifth Assessment Report
CERES	Crop Environment Resource Synthesis
CSMK3	Commonwealth Scientific and Industrial Research Organisation
DNRAE	Department of Natural Resources and Environment
DRRM-CCA	Disaster Risk Reduction Management and Climate Change Adaption
DSSAT	Decision Support System for Agrotechnology Transfer
GCMs	General Circulation Models
Ha	Hectare
Had GEM	Hadley Centre Global Environment Model
HadCM3	Hadley Centre Coupled Model version 3
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
Kg	Kilogram
Km^2	Square kilometer
Lao PDR	Lao People's Democratic Republic
m	Meter
m^3	Cubic meter
MRC	Mekong River Commission
s	Second
SWOT	Strengths, Weaknesses, Opportunities, Threats
UNDP	United Nations Development Programme
UNESCO-IHE	United Nations Educational, Scientific and Cultural Organisation-Institute for Water Education
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World Wildlife Fund

CHAPTER I
INTRODUCTION

1.1 Background

The rainfall patterns that farmers depend on are being increasingly disrupted by changing climatic conditions, particularly precipitation and atmospheric moisture. This is due to a combination of changes in atmospheric circulation, a more active hydrological cycle, and increasing water-holding capacity throughout the atmosphere (Dore, 2005). Among other impacts, seasonal variability is increasing and extreme rainfall events are intensifying, so that as noted by Dore: “we observe that wet areas become wetter, and dry and arid areas become more so” (2005, p1167), requiring new coping strategies. Rice production in tropical regions is facing a range of challenges from global warming such as water shortages and other factors that limit the capacity of farmers to grow the crop (e.g., Horie et al., 1996; Peng et al., 2004; Tao et al., 2007). Therefore, the vulnerability of rice production to global warming has become of key concern both currently and also in the future. Many studies have used crop models and several climate-change scenarios to simulate the impact of climate change on rice production in Asia (e.g. Kropff et al., 1993; Horie et al., 1997; Matthew et al., 1997; Aggarwal and Mall, 2002). A large majority of the rural population of Lao PDR (approximately 72 percent according to recent government statistics (LSB, 2015)) remains dependent on agriculture, as well as forestry and fisheries, for their livelihoods and food security, and access to and management of both irrigated and rain-fed water sources is critical. Crop choices and planting calendars follow a monsoonal (dry season/wet season) weather system, and are very vulnerable to deficits of rainfall in the dry season and oversupply in the wet season.

Lao PDR is highly challenged by this situation because of the combination of low state capacity to respond (including technical knowledge and budget) and lack of systems to predict or control drought or flood. Several large-scale modeling studies have been carried out in Lao PDR, including a simulation of climate change impacts on lowland paddy rice production potential in Savannakhet Province. This study applied the DSSAT CERES-Rice model under three General Circulation Models (GCMs) such as CSMK3, HadCM3 and Had GEM with high and low climate sensitivity, respectively (Boulidam, 2012). The results show that rice yield (of the same selected cultivar) under all six climate change scenarios will increase between +6.8% and +12.8% compared with observation years (1995 to 2009). Adaptation in rice farming practices may include cultivar change, soil preparing, sowing and transplanting date, weeding, timing and amount of fertilization. Farm technologies and cultivar breeding supporting local rice farming will be further challenged beyond the farm level to ensure or further increase rice production for future climate change conditions (Boulidam, 2012). According to the International Panel on Climate Change (IPCC, 2007), climate change projections show that flood vulnerable areas like Savannakhet Province might face worse problems in the future. IPCC's Fourth Assessment projected an enhanced hydrological cycle and an increase in area-averaged annual mean rainfall over Asia. The study also projected that higher rainfall intensity, particularly during the summer monsoon, could increase flood-prone areas in temperate and tropical Asia (IPCC, 2007).

Economic development will require more food production in agriculture to support human consumption (FAO, 2003). The lack of solutions to both flood and drought in the central and southern part of Laos where Savannakhet province is located can limit agricultural development. This province has the largest paddy rice cultivation area in Laos, which covers 21.48 % or 194,157 hectares of the country's total area of paddy rice cultivation (MAF, 2009). Over-supply of water causing flood during rainy season, and lack of water supply in the dry season are still the main challenges for farmers. A recent flood vulnerability assessment in Champhone district, Savannakhet province showed the level of vulnerability in 10, 20 and 50 year return periods which affects 629,646 ha and 668 km^2 areas respectively. Depths greater than 6m were considered as very high and the area having such a depth was found to be 179,414 ha and 433 km^2 for 10, 20 and 50 year flood (Hazarika et al. 2008). Farmers still lack water during dry season however, as they could not access irrigation, and a climate change adaptation project conducted in Champhone district in 2003 identified the need to develop irrigation, but was able to expand just 1000 m of irrigation canal, which could not cover all farmers in the surrounding area due to limited budget (MRC, 2014a). This shows that water storage methods and tools to keep water from the rainy season to use in the dry season are very important for local people in terms of food security and income, but these methods and tools have to be based on local capacity and also have to especially consider their economic constraints. This study will review the evolution of approaches to vulnerability assessment related to water resources. The results of the study identify the current main constraints (e.g., lack of institutional coordination) and methods opportunities (e.g., adaptation) of the Xe Champhone River. This study aims to contribute to innovative research and management initiatives of small-scale water resources systems in Lao PDR.

1.2 Statement of the Problem

The local population in Champhone district consists mainly of rural farming families, with rice as their most important food crop which also provides income for some people. These communities depend on the Xe Champhone River for irrigation of crops during rainy season, but when the water level is too high their crops can often be destroyed. Local livelihoods are therefore very vulnerable to flood impacts, while in the dry season the community often lacks water supply to their crops.

One example extreme heavy rainfall and flooding event took place from July to October 2011, leading to population displacement, loss of crops on about 4,445.11 hectares, soil erosion, and the destruction of about 10,021 houses. During the peak of the flooding, there were about 10,536 Internally Displaced People (IDPs), with 1,210 living within three IDP camps and the rest staying with family and friends. Crop damage was substantial. Each time there is flooding, farmers cannot produce their crops. The high water level damages their properties and production such as crop areas, livestock and especially rice fields. After flooding people will have not enough food stock for consumption. Flooding affects both the rice quality and quantity and leads to food insecurity in the communities.

People living far from irrigation are unable to manage their water supply, which in the context of climate variability affects both food insecurity and income, since vulnerable farmers are forced to change from selling their harvest to buying from other areas to continue accessing food. Instead of waiting for budget to manage water supply by irrigation methods, other countries facing similar problems (e.g. Nepal, Rockstrom, 2007) have tried community-based water management methods to find ways to store the water but this can be expensive. The aim of the present study is to find low cost options to store water that will be appropriate to local conditions.

1.3 Originality of the Research

This study considers the evolution of approaches to vulnerability assessment related to water resources, and aims to contribute to innovative research and management initiatives of small-scale water resources systems in Lao PDR. The main contribution of the research design is to combine study of climatic conditions with analysis of social data and institutional capacity at different scales, with the aim of supporting community members to identify ways to protect their water supply against climate variability through storage methods, and also to understand rainfall variability and how to adapt crop types. The results of the study identify the current main constraints (e.g., lack of institutional coordination) and methods opportunities (e.g., adaptation) applicable for communities that depend on the Xe Champhone River. Economic development will require more food production in agriculture to support human consumption (FAO, 2003). The lack of solutions to both flood and drought in the central and southern part of Laos where Savannakhet province is located, can limit agricultural development. This province has the largest paddy rice cultivation area in Laos, which covers 21.48% or 194,157 hectares of the country’s total area of paddy rice cultivation (MAF, 2009). Oversupply of water causing flood during rainy season, and lack of water supply in the dry season are still the main challenges for farmers. A recent flood vulnerability assessment in Champhone district, Savannakhet province showed the level of vulnerability in 10, 20 and 50 year return periods which affects 629,646 ha and 668 km^2 areas respectively. Depths greater than 6m were considered as very high and the area having such a depth was found to be 179,414 ha and 433 km^2 for 10, 20 and 50 year flood (Hazarika et al., 2008). Farmers still lack water during dry season however, as they could not access irrigation, and a climate change adaptation project conducted in Champhone district in 2003 identified the need to develop irrigation, but was able to expand just 1000 m of irrigation canal, which could not cover all farmers in the surrounding area due to limited budget (MRC, 2014a). This shows that water storage methods and tools to keep water from the rainy season to use in the dry season are very important for local people in terms of food security and income, but these methods and tools have to be based on local capacity and also have to especially consider their economic constraints.

1.4 Research Objectives

The research has been designed to enable community members to identify ways to protect their water supply against climate variability through storage methods and also to understand rainfall variability and how to adapt crop types. It will also provide information to assist with projects aimed at sustainable and safe community water use in Lao PDR for the future, to help communities cope with climate change impacts that may affect their water resources and prevent loss of crops. The specific objectives of this study were as follows, on which the results and conclusion (chapters IV and V) are based:

a) Assess localised impacts of climate change in communities along the Xe Champhone River, especially the impacts of seasonal rainfall variations on crop production.
b) Identify community adaptive capacity against climate variability, through water storage methods, and also to understand rainfall variability and how to adapt crop types.
c) Identify community adaptation options to ensure rice security, social welfare and support livelihoods.

d) Provide research aimed at sustainable water management in Lao PDR for the future, to assist other projects and help communities cope with climate change impacts that may affect their water resources and prevent loss of crops.

1.5 Research Questions

A multi-methods approach was planned that would combine household surveys with climate modeling based on district and provincial scale historic data and projections to examine the following research questions:

1. How are households affected by flooding and drought in Champhone district, Savannakhet province, Lao PDR?
2. What are the historic trends regarding flooding and drought, and how are these likely to be affected by climate change?
3. What coping strategies are currently used by farmers? Why are these the most appropriate in the local conditions?
4. What are the factors that can be improved to strengthen adaptive capacity and resilience to climate change?

1.6 Hypothesis of the study

In response to the background information, problem framing, objectives and research questions set out above, the hypothesis of the study is as follows. This was based on the main forms of climate change vulnerability faced by the study communities, current adaptive capacity, and potential adaptation measures that are possible to implement in the studied environment, while considering budget constraints.

- Variable rainfall conditions and the extent of flooding from the Xe Champhone River make farmers more vulnerable to climate change impacts on their crop production, especially rice.
- Development of irrigation systems would provide enough water for dry season crops with higher yields to secure rice supply, though this requires public investment. Changing crop planting cycles and varieties during the rainy season could also minimise flood impacts on rice production.
- Methods of water harvesting during extreme rainfall could support people to reduce climate change vulnerability, by managing water balance and storing water for later use to improve their livelihoods.

1.7 Significance of the Study

The significance of the research is to understand how local livelihoods can adapt to the situation, reduce their vulnerability and what can be done to improve water use management in the communities. Weather data and climate change studies show that flooding in Champhone district might increase in future, and projects in the local area have been working on how to adapt to the impacts. This research will provide baseline information to development organisations in this area for the future and lessons learned from the country and outside will support this research to review the available information, and make recommendations about how the vulnerable communities can adapt to the situation both now and in future.

1.8 Scope and Limitations of the Study

The research has been designed to create a method for community members to identify ways to protect their water supply against climate variability through storage methods and also to understand rainfall variability and how to adapt crop types. The study will focus on the possibility of community water management based on resources and capacity available in Champhone District, Savannakhet Province, according to constraints on time, funding, distance and resources.

The study sites were also not within the worst-affected areas but nevertheless are very significant locations to study in terms of heavy rainfall and resulting flood events due to changing climate. In this regard, some of the key data were limited to rainfall as long as ground water as well and those related to flood periods.

1.9 Conceptual Framework

Household welfare and vulnerability can be highly impacted by variable rainfall. Vulnerability is defined as the extent of harm which can be expected under certain conditions of exposure, sensitivity and resilience (Figure 1). Physical Vulnerability pertains to the man-made environment of infrastructure and the natural environment of agriculture and forest. Vulnerability is not only related to exposure to hazards (perturbations and stresses), but also the sensitivity and resilience of the system experiencing such hazards. Frequent high rainfall events in Champhone District will likely contribute to further flooding disasters in future.Variability in the amount and distribution of rainfall is the most important factor that limits yield of rainfed rice in these conditions.

Flooding in this area will affect lowland rice through its production systems and area for cultivation. If this occurs continuously without any adaptive measures, it is directly impact on food security. Meanwhile flooding in the area will indirectly affect livelihoods through reduced income. Adaptation measures are hence needed to minimise the impacts of flooding disasters.

Examining the vulnerability of these systems to climate change also includes the physical capacity of buildings to cope with external forces. Examples of the factors necessary to determine the magnitude of physical vulnerability include: location (whether areas are disaster prone); level of exposure (of the city, village, community, houses, farmland, etc.); and elements at risk, including people, settlements, roads, bridges etc. Further, elements of vulnerability include: fragility of livelihoods; poor access and control over means of production (capital, land, animals, etc.); dependence on money-lender/agents; inadequate economic fall-back mechanisms; occurrence of acute or chronic food shortages; lack of adequate skills and educational background; lack of basic services (education, health, drinking water, shelter, sanitation, roads, electricity and communication systems, among other); high mortality rates, malnutrition, occurrence of diseases, insufficient caring capacity; overexploited natural resources; and domestic violence or community conflicts (NIDM and NDMA, 2010).

On the other hand, reducing flood vulnerability can also be supported by increasing the production of crops in the dry season if there is water available. Together with vulnerability assessment, evaluating water availability can identify the possible methods for water management to improve the resilience of farming mechanisms, particularly when the local community depends on rainfed crops. The studied communities have high poverty levels, limited adaptive capacity, and high sensitivity to flooding. These require determination of vulnerability and immediate risks more than long-term impacts of climate change. National governments have a specific role in establishing the policy and regulatory environment to encourage adaptation by individuals, households and private sector businesses. They can strengthen the knowledge base of climate risk assessments and strengthen the early warning chain of climate change trends, seasonal forecasts and weather alerts from satellites to national radio stations to local village announcement systems and cell phones (Sweta, 2014).

The present research identifies water harvesting methods for reducing the vulnerability of the communities/sectors to the impacts of rainfall variability. This can contribute to baseline information for policy-makers, other vulnerable communities, donors, and civil society with the aim of leading to concrete action to improve adaptive capacity, reduce vulnerability, and strengthen the livelihoods of the affected communities by improving farm production. The research will further support decision-makers in evaluating adaptation options and water management in local areas.

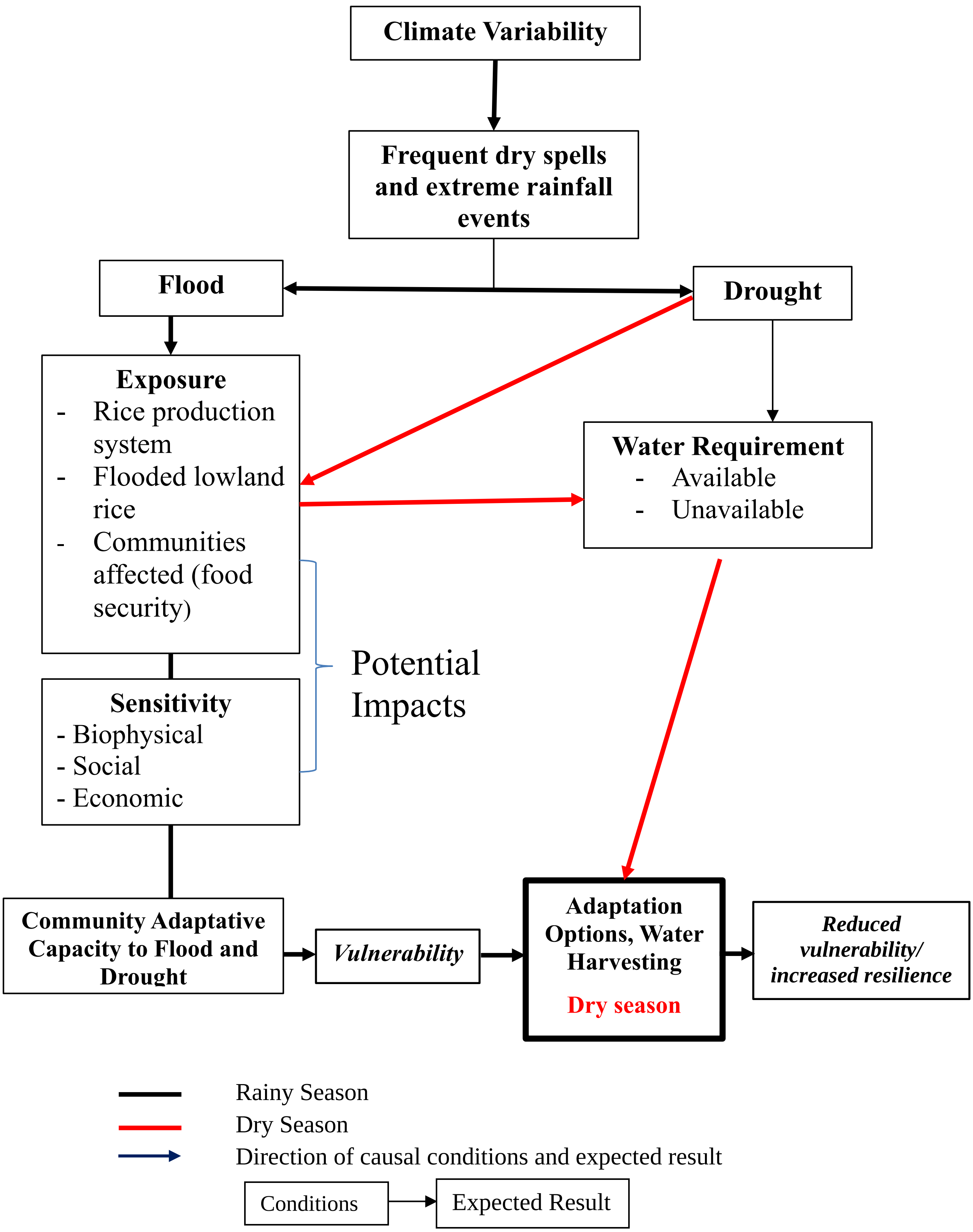


Figure 1. Conceptual Framework of the Research.

CHAPTER II
REVIEW OF LITERATURE

2.1 Climate Change

The current literature on climate change and related potential threats to food production systems and livelihoods and food security is large and varied. Perhaps the most important issue for the purposes of the present study is the risks presented by climate change to about one billion people who depend on agriculture for subsistence and income in the Asia-Pacific region. While there is now a large amount of related terminology, useful key definitions of the term "climate change" are provided by the United Nations Framework Convention on Climate Change and IPCC (2007) as follows:

"Climate change is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods" (UNFCCC, 2007); and "Any change in climate over time, whether due to natural variability or as a result of human activity" (IPCC, 2007).

2.2 Complex Extreme Events

One of the major concerns linked with climate change is the potential for increased extreme events in terms of both frequency and intensity. Extreme events are often the consequence of a combination of factors that may not individually be extreme in themselves. Such events occur at different scales in space and time, which is important to the present study in terms of assessing the impacts of extreme rainfall. Equally, complex extreme events, including flooding, are often preconditioned by pre-existing, non-extreme conditions. IPCC also notes that non-climatic factors often have roles in complex extreme events, such as air quality extremes (in urban settings) that result from a combination of high temperatures, high emission of smog precursors, and stagnant circulation. Crucially, complex extreme events often have very high socio-economic and environmental impacts, by which the poor and most vulnerable are worst affected (IPCC, 2002).

2.3 Impacts on Biological Systems

According to observations from a wide range of species, there is evidence that recent global warming is strongly affecting terrestrial biological systems, such as earlier timing of spring events, leaf-unfolding, bird migration and egg-laying; and pole-ward and upward shifts in the ranges of plant and animal species (IPCC, 2007). These changes in ecosystem composition will alter farming practices over time, for example in terms of crop varieties farmers can plant in the prevailing conditions and what pest types they face.

2.4 Change in the Seasonal Cycle

A key long-term change that is crucial for rural farmers in developing countries to adapt to is seasonal variations resulting in changes in cropping cycles. Extreme forces within the climate system, whether anthropogenic or natural in origin, will result in changes in the annual cycle of surface temperatures, which can be detected by monitoring the amplitude of the annual cycle and the dates when the annual maximum and minimum temperatures occurred. Slow variation in the climatologically mean, as indicated by change in the amplitude and shape of the annual cycle, will impact on the frequency and intensity of extremes on both daily and monthly time scales (IPCC, 2002).

2.5 Rice Yield Impacts

Climate change alters temperature and precipitation patterns, both of which have direct effect on crop production and indirect effects through changes in irrigation water availability and evapotranspiration potential. Rainfed crop yields are directly affected by changing temperature and precipitation, while irrigated crop yields are directly affected by temperature effects alone and by indirect effects of water availability through irrigation-related changes in water availability (ADB, 2009).

2.6 Global Climate Changes and Rice Food Security

Nguyen (2009) places rice food security in the face of the yield impacts mentioned above in the global context, in which at present about 40 percent of the total rice production area is classified as rainfed (lowland or upland), while about 3.5 million ha remain classified as deep-water or flood-prone. For rainfed rice, variability in the amount and distribution of rainfall is unsurprisingly found to be the most important factor limiting yields, as well as a determining factor in the variation of planting practices. Variability in the onset of the rainy season also leads to variation in the start of the planting season for rainfed rice, while in freely drained uplands, moisture stress severely damages or even kills rice plants in areas receiving as much as 200 mm of precipitation in one day and then no rainfall for the next 20 days. Complete crop failure usually occurs when severe drought stress takes place during the reproductive stages. Flood is the most important inhibiting factor to rice production in low-lying areas, such as the focal area of the present study. Most rice varieties for rainfed lowland, irrigated and deep-water ecosystems can stand complete submergence for at least 6 days before 50 percent die, but this increases to 100 percent when submergence lasts 14 days. Floods also cause indirect damage to rice production through the destruction of property, means of production and related infrastructure, such as dams, dikes and roads. It was also noted by the IPCC and others that changes in the pattern of rainfall distribution may lead to more frequent and intense flooding and drought in different parts of the world under a changing climate (Nguyen, 2005).

2.7 Climate Change Adaptation Research

Adaptation to climate change can be seen in terms of the alteration in the state of a system that arises in response to the stressor introduced by changes in climatic contributions, under which key variables are conserved or enhanced (Pelling and High, 2005). The idea of conservation of key variables is important in providing a bottom line, below which would appear degradation rather than adaptation.

Francisco (2008) suggested that the answers to what Climate Change Adaptation (CCA) research should address can reflect a shared vision of what good CCA research should be. This has three key elements: focus, scope and approach. The focus of CCA research is to target vulnerable poor communities/sectors and respond to the needs of the users of the research information (policy-makers, vulnerable communities, donors, and civil society), generate findings that not only add knowledge but also lead to concrete action to improve adaptive capacity and livelihoods, and reduce vulnerability of the affected communities. Research should further support decision-makers in evaluating adaptation options, including economic considerations. The scope of a good research study on climate change adaptation should consider the issue in relation to the Millennium Development Goals (or the subsequent proposed Sustainable Development Goals) and national development goals such as sustainable development and poverty alleviation. Such a study should also consider the cross-sectoral impacts of climate change and adaptation interventions as well as assessing the sustainability of such interventions, and should not be limited to the evaluation of adaptation options. These should also consider implementation issues like transparency, particularly in the case of planned community adaptation. The approach of the research should be science-based, adopting an interdisciplinary approach to allow for comprehensive analysis (Francisco, 2008).

2.8 Flooding Impacts on Rice Production Systems

Around 12.8 million ha of rice production land mostly in South and Southeast Asia are subject to uncontrolled flooding. Of this area, 11.4 million ha are included in the International Rice Research Institute’s (IRRI) classification of flood-prone ecosystems. Rice yields are low and extremely variable in these conditions because of problem soils and unpredictable combinations of drought and flood. Although average yields are only about 1.5 T/ha, these areas support more than 100 million people.

The flood-prone ecosystem has many different environments and incorporates many types of rice. These rice varieties must be adapted to conditions such as temporary submergence for 1-10 days, or longer periods (1-1.5 months) of standing (stagnant) water ranging with a depth of 50 to 400 cm or more, or daily tidal fluctuations that sometimes may also cause complete submergence. In most of Asia, flooding occurs during the wet season months of June to November (IRRI, 1997).

Plants require water for growth but excess water that occurs during submergence or water logging is harmful or even lethal. A submerged plant is defined as “a plant standing in water with at least part of the terminal above the water or completely covered with water” (Catling, 1992). Submergence subjects plants to the stresses of low light, limited gas diffusion, effusion of soil nutrients, mechanical damage, and increased susceptibility to pests and diseases (Greenway and Setter, 1996; Ram et al., 1999). Flooding (i.e. submergence) can be classified into “flash flooding” and “deep water flooding” in accordance with the duration of flooding and the water depth (Catling 1992; Jackson et al., 2003; Bailey-Serres et al., 2010). Flash flooding, which generally lasts less than a few weeks, is caused by heavy rain but the depth is not very deep. On the other hand, deep water flooding, which lasts for several months, occurs during the rainy season, and the water depth reaches several meters (Catling, 1992; Hattori et al., 2011).

2.9 Vulnerability

Vulnerability can be defined as the state of a system before an event (Sebald, 2010). People are more vulnerable if they are more likely to be badly affected by events outside their control (Action International, 2003). Vulnerability is a term with many meanings that depend on the specific topic, but the basic concept behind it is the relationship between the hazardousness of place and the components which are likely to be affected. Sebald (2010) further discussed that the ingredients of vulnerability are the major characteristics including how society is made up, and how it reacts when hazardous impacts take place. However, vulnerability is registered not by exposure to hazards (perturbations and stresses) alone but also resides in the sensitivity and resilience of the system experiencing such hazards. Therefore, vulnerability can now be defined as the extent of harm, which can be expected under certain conditions of exposure, susceptibility and resilience (UNESCO-IHE, 2007).

Physical vulnerability. Physical vulnerability pertains to the man-made environment of infrastructure and the natural environment of agriculture and forest. This does not solely consider the geographical location of actors and assets in the area (population, buildings and crops). It also includes the physical capacity of buildings to cope with external forces. Examples of the factors necessary to determine the magnitude of physical vulnerability include location (whether areas are disaster prone); exposure (of the city, village, community, houses, farmland, etc.); elements at risk including people, settlements, hospitals, roads, bridges etc.; fragility of livelihoods; poor access and control over means of production (capital, land, animals etc.); dependence on money-lenders/agents etc.; inadequate economic fall-back mechanisms; occurrence of acute or chronic food shortages; lack of adequate skills and educational background; lack of basic services (education, health, drinking water, shelter, sanitation, roads, electricity, communication systems etc.); high mortality rates, malnutrition, occurrence of diseases, insufficient caring capacity; overexploited natural resources; and domestic violence or community conflicts (NIDM and NDMA, 2010).

Social vulnerability. Social vulnerability can be referred to a rather specific and yet multifaceted entity with many different characteristics and attributes (Sebald, 2010). Factors that can be considered under social vulnerability include demographic concerns and level of awareness of risks. Issues that can be taken into consideration are as follows: vulnerable categories of people including single parents, women, pregnant women and physically challenged individuals, children and the elderly; population density which has a strong correlation with casualties; common perceptions and beliefs of the community about hazards, their impacts and corresponding mitigation measures; and weak family/ kinship structures (NIDM and NDMA, 2010).

Economic vulnerability. Economic vulnerability meanwhile pertains to the people's niche, activities, or ways on how they make their living (NIDM and NDMA, 2010), or it occurs when national economies or those of other entities are at risk from negative impacts arising from external forces (Ursula et al., 1999). The key issues to be considered in determining the magnitude of economic vulnerability are the types of livelihood that are easily affected by disasters.

Vulnerability assessment. Vulnerability as defined can be generalised as a complex combination of interrelated, mutually reinforcing and dynamic factors (Actionaid International, 2003). UNDP (2010) stated that vulnerability assessment is done to determine the capacity of elements at risk to withstand the given hazard scenarios. In a light way, it identifies what elements are at risk and why (WWF-Pakistan, 2011). Actionaid International (2003) added that assessment or analysis of vulnerability is a predictive judgment since the nature of vulnerability is dynamic and complex and cannot be analyzed directly.

There are several approaches to analyzing vulnerability. It can be trimmed down to quantitative or the use of quantifiable characteristics. Further, vulnerability assessment is the second phase of assessing hazards which combines information from hazard identification with elements at risk, such as property, population, households, and others. The purpose of this assessment is to provide essential information to whom and what entities are vulnerable to a given hazard within the concerns related to geographical location. This can be used to estimate damage and casualties when hazard occurs (Actionaid International, 2003). According to Sebald (2010), it can also be used as a tool to improve plans concerning disaster risk reduction and management.

2.10 Assessment of vulnerability to flooding

According to UNESCO-IHE (2007), flood vulnerability is the extent to which a system is susceptible to flooding due to exposure and perturbation, in conjunction with its ability (or inability) to cope, recover, or basically adapt. Applying a systems approach which aims to identify the interactions of different components acting in a system within defined boundaries can determine how flood affects the water resource system of an area. Floods can be considered as a disruption in normal functioning of the water resource system, such as when flooding occurs in cities it may damage water quality and could cause other damages to property and life (Sebald, 2010). Flood vulnerability comprises four approximate categories/dimensions: The first is the social vulnerability of the people; those within the society who are likely to suffer most from potential losses from flood events. Second is economic vulnerability, which covers different factors including population size, remoteness of place, nature of agriculture, forestry, access to goods and services etc., and can be described as the source of income in the place. The third category is the ecological dimension, concerning conservation and degradation, over exploitation, displacement by invasive alien species and global climate changes, which are the main processes that affect biodiversity. Finally, the physical vulnerability of the built environment, including infrastructure, etc. Each of these dimensions makes up the different sides to establish a flood vulnerability index (Sebald, 2010).

The components can be assessed by different indicators to understand the vulnerability of the system to floods (Sebald, 2010). These components of vulnerability are functions of the three common factors of exposure, susceptibility of the system to flood, and ability/capacity/resilience of the system to cope, adapt and/or recover from flood. Each vulnerability factor represents a set of indicators, which can help to better understand the weakness of an area to flood (UNESCO-IHE, 2007).

2.11 Adaptation and Social Learning

Adaptation measures to flood are often based on local experiences and perceptions. These include construction of houses in elevated areas or with high foundations to avoid flood water, adjustment of production activities, changes in crop choices, reinforcing existing house structures, moving to safer places, sandbagging potential flood sources, storing or sharing food, changes in livelihood options and temporary migration. Despite these efforts, capacity to adapt to climate change/variability by local communities remains limited, including at the national level. Some researchers recommend building the ability of communities and local governments to predict and monitor climate change impacts. Two case studies in Vietnam and Philippines have proposed mainstreaming adaptation and risk management strategies into community development plans and promoting community and multi-stakeholder participation as a way to manage the risks arising from climate change (Francisco, 2008).

2.12 Local Coping Strategies

There is a large body of knowledge and experience within local communities on coping with climatic variability and extreme weather events. Local communities have always aimed to adapt to variations in their climate. To do so, they have made perceptions based on their resources and knowledge accumulated through experience of past weather patterns. These include times when they have also been forced to react to and recover from extreme events such as floods, droughts and storms. Local coping strategies are important elements of planning for adaptation. Climate change is leading communities to experience climatic extremes more frequently as well as new climate conditions and extremes. Traditional knowledge can help provide efficient, appropriate and time-tested ways of advising and enabling adaptation to climate change in communities. In Asia, farmers are using intercropping, mixed cropping, agro-forestry, animal husbandry, and developing new seed varieties to cope with changes in local climate (UNFCC, 2007).

2.13 Water harvesting systems

Water harvesting in its broadest sense can be defined as the collection of runoff for its productive use. Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses. Water harvesting techniques, which harvest runoff from roofs or ground surfaces fall under the term ‘rainwater harvesting’ while all systems which collect discharges from watercourses are grouped under the term ‘floodwater harvesting’ (AfDB, 2013).

Water harvesting is the key to making better use of rainwater for agricultural purposes: it increases the amount of water available per unit of cropping area, reduces the impact of drought, and uses runoff beneficially. Water harvesting is based on the principle of depriving part of the land of its share of rain, which is usually small and non-productive, and adding it to the share of another part. This brings the amount of water available to the latter area closer to crop water requirements and thereby permits economic agricultural production. Water harvesting may occur naturally or by intervention. Natural water harvesting can be observed after heavy storms, when water flows to depressions, providing areas for farmers to cultivate. Water harvesting by intervention involves inducing runoff and either collecting or directing it, or both, to a target area for use. Besides being applied to agriculture, water harvesting may be developed to provide drinking water for humans and animals as well as for domestic and environmental purposes. According to Oweis et al. (2001), water harvesting methods are classified in several ways, mostly based on the type of use or storage, but the most commonly used classification is based on the catchment size.

Micro-catchment Systems

Micro-catchment systems are those in which surface runoff is collected from a small catchment area, with mainly sheet flow over a short distance. Runoff water is usually applied to an adjacent area of farmland, where it is either stored in the root zone and used directly by plants, or stored in a small reservoir for later use. The target area may be planted with trees, bushes, or with annual crops. The size of the catchment ranges from a few square meters to around 1000m^2.

Land catchment surfaces may be natural, with vegetation intact, or cleared and treated in some way to induce runoff, especially when soils are light. Non-land catchment surfaces include the rooftops of buildings, courtyards and similar impermeable structures (Oweis et al., 2001). In rural catchments faced with water surplus and deficits, water harvesting through on-farm measures is a very important form of adaption (Subagyono at al., 2008).

On-Farm Systems

On-farm micro-catchment systems are simple in design and can be constructed at low cost, making them easy to replicate and adaptable. Micro-catchment systems have higher runoff efficiency than macro-catchment systems, and also do not usually require a water conveyance system. However, on-farm systems often need continuous maintenance and therefore have relatively high labour requirements, though all aspects of the system are constructed inside the farm boundaries. This is an advantage in terms of management and maintenance, but does also mean the loss of productive land. On-farm micro-catchment systems are commonly only used in drier environments, where risks to cropping are highest, so farmers are willing to allocate part of their farmland to a catchment **(**Oweis et al., 2001). Key water harvesting measures include channel reservoirs, on-farm reservoirs, dikes, infiltration ditches and wells (Subagyono et al., 2008). The application of the harvested water is also differentiated by supplemental irrigation (storage for repeat application at different stages of the cropping season) and runoff farming, or diverting surface water to fields (Falkenmark et al., 2001), in which higher costs may be involved for farmers depending on the amount of needed construction.

2.14 Existing on-farm water management in Southern Lao PDR and comparative cases in similar climatic conditions

Southern Laos

Although Laos is water-abundant relative to other countries in Asia, because of variability in rainfall and competition over surface water resources between farming and other sectors (e.g. mining, hydropower), there are signs that pressure on groundwater is beginning to increase in the southern provinces (Vote et al., 2014). Groundwater pumping has also become more accessible for domestic use and small-scale irrigation because of the recent expansion of Laos' electricity grid and cheap pumping systems, enabling farmers to apply groundwater to support early planting/double cropping in the rainy season (a key farmer-driven trend in rainfed rice systems across Asia (Roth, 2014)). As development of groundwater increases in southern Laos, this may bring the possibility of abstraction at greater volumes for irrigating dry season crops, increasing the importance of understanding and managing the extent of groundwater use to avoid compromising future sustainability (Vote et al., 2014). Roth observes that "in both Cambodia and Laos there is increasing debate about the merits of large irrigation schemes versus smaller, decentralised, farmer-driven irrigation systems", and strong potential exists for "natural and artificial water-harvesting structures to support supplementary [wet season] irrigation" (2014: 90). This may significantly reduce climatic risks towards the main rainy season rice crop and offer more cost-effective intensification than is provided by conventional irrigation for the dry season crop (Roth, 2014), as well as avoiding risks of increased groundwater pumping. Common existing applications of rainwater harvesting in Laos mainly focus on storage in pots or small tanks for household use and small on-farm ponds, mostly for aquaculture, while short-term rainwater storage for drinking water is also common in locations where people cannot access piped water. Where piped water is available, rainwater is still often harvested for household use and gardening, mainly to reduce costs. Initial studies into climatic risks and possible adaptive measures for smallholder farmers in Savannakhet province have identified priority adaptations as piloting flood tolerant rice in the rainy season, adjusting planting cycles, and constructing small-scale reservoirs, water storage tanks and sinking groundwater bores to allow for dry season production (MRC, 2014a).

Also focusing on Savannakhet province, Inthavong et al. highlight water availability and soil fertility as two key factors that cause variations and limits to rice productivity (2011). The study observes high variation in rainfall within the province, and also variation in the presence and duration of standing water needed for paddy cultivation, because of soil clay content, rates of percolation and lateral flows to lower fields. Another key factor in water availability was the variation in early-season rainfall, with “a large influence on the spatial variation in field water availability, which contributed to the year-to-year variation in time of sowing and therefore transplanting” (194). Studying farm practices of more than 100 households over two cropping seasons, Inthavong et al. found that “rainfall distribution pattern, soil type and position of rice fields on a sloping land, affect paddy water availability, and this in turn influences sowing time and is also expected to have effect on grain yield” (2011: 184). Because of the overall low soil fertility, the findings show that improving only water availability will not provide a significant increase in rice productivity. The study recommends that improved yields will require combining “appropriate crop phenology, increased fertiliser use that is matched with water availability, and an understanding of soil fertility” (Inthavong et al. 2011: 184). Fertiliser application was found to be below recommended levels, which was due to understanding of risk of drought and flooding, the lack of fertilisers at the right time and high investment costs for poor farmers. Inthavong et al. recommend quantifying water balance to understand variable impacts of fertiliser application (2011). Although it is outside of the scope of the present study to model soil fertility and fertiliser benefits, by analysing water balance this research can help to support farmer decision-making on fertiliser application and other factors of rice production in Champhone district. An effective first step towards more stable water resources in Champhone district can be achieved by applying on-farm storage techniques such as reservoirs.

Indonesia

In Indonesia, like most countries of Southeast Asia, food security is very strongly connected to rice. The International Rice Research Institute (IRRI) estimates that Indonesia will need 38% more rice in the next quarter century. This means that the current level of rice production, at about 50 million tons per year, will need to rise to about 70 million tons by 2025 (IRRI, 2011). Only 34% of Indonesia’s agriculture land is covered by irrigation, of which the total area of irrigated paddy fields is 4.14 million hectares (Hendrayanto, 2004). Because significant farm area is rainfed, even though Indonesia is very different to Laos geographically as an island nation, farmers there face similar vulnerabilities to farmers in Laos. To structurally mitigate flood hazard impacts, around 600 rivers require about 30,000 km of river training and 15,000 km of dike construction. However, the capacity and budget constraints of the government mean that only about 1% of these structural mitigation measures have been developed, or river trainings and dikes totaling about 300 km and 150 km, respectively. Meanwhile, droughts have caused about 250,000 farming families who depend on rice to suffer from a decrease in production (Fulazzaky, 2014). Moreover, drought often affects the second crop of irrigated and rain-fed rice fields (Raman et al., 2012). Therefore, water management needs to be expanded based on building local capacity.

Because communities are aware of the deteriorating water availability, they have made local adaptation efforts to obtain water to cover their needs, such as rainwater harvesting, which has been developed by local communities for many uses, including agriculture. Common techniques of rainwater harvesting are collecting either surface or sub-surface flow to store during wet periods for use in dry periods, applying harvesting systems such as channel reservoirs, on-farm reservoirs, infiltration ditches, infiltration wells, check dams and water harvesting dikes.

One example is Selopamioro, Bantul, Yogyakarta. Research found that a small reservoir with the dimensions of 7m x 2.5m x 3m and capacity of about 52.5m^3 (Figure 2) can contribute to an increase in rainfed rice production of up to 176%, or increased production from 4,230kg to 11,700kg. The cultivated area used for this mini-water storage pond was not more than 7% of the total cultivated area (Subagyono and Pawitan, 2008).

Figure 2. On-farm reservoir, Indonesia. Source: Subagyono and Pawitan (2008).

Cambodia

Similarly to Laos, the livelihoods of more than 74% of the Cambodian population depend on agriculture and fisheries. But more than Laos, food security in Cambodia has traditionally had two dimensions: rice and fish, with fish being a main source of protein and central aspect of rural livelihood strategies for Cambodian people. More than 80% of the total animal protein in the Cambodian diet is estimated to come from fish and other aquatic animals, especially from inland water bodies, namely paddy fields, rivers, streams, natural lakes and community ponds (Joffre et al., 2010). Policy analysis also promotes rice as a potential export product to support agricultural and rural development in Cambodia (De Silva et al., 2014), but Cambodia faces many similar climatic risks to Laos that will affect future production. In particular, many regions face lack of water for production, especially in coastal-sandy regions, where fresh water supplies are lacking and people often face water-scarcity in dry seasons.

Digging on-farm ponds to harvest rainwater for irrigating crops during dry periods provides a means for addressing shortages of water at the start of crop cultivation, both before the start and after the end of the rainy season, to increase the duration of the potential growing season for crops. In areas with low rainfall and limited or lack of irrigation system, rainwater harvesting to increase irrigation potential is important for crop cultivation, income and food security. Research in similar conditions to Laos shows that potential seasonal drought can be alleviated while increasing crop cultivation and aquaculture in Cambodia with basic ponds of approximately 40m x 20m surface are and 4m depth (WOCAT, 2017). Similar to in Laos, the farmers in the Cambodian study received less than 10% of all income from off-farm work, and more than 90% of the local population was involved with agriculture. The results showed that sufficient water was available for irrigating crops outside the period of regular cropping, based on rainfall distribution and harvesting to store water for irrigation in the dry season and for use during periods of drought. One challenge was the significant cost of digging such ponds, which are expensive due to their relatively large scale, and also need to be restored every few years. Farmers therefore may need external support, including from projects and non-government organisations, which can support rice as a product promoted for export in the Cambodia strategy (WOCAT, 2017)

Improving water-management approaches in agricultural conservation is likely to be the center of adaptation strategies in dry-land agriculture. However, these technical innovations have not been sufficient on their own because local conditions and capacity still have many limitations, especially in coastal and sandy soil areas where the poverty rate of poor households is still high and because of low capacity for investment in technical innovations, which is similar to Laos.

Vietnam

Vietnam has many similarities to Laos in terms of agricultural systems and livelihoods, particularly relating to rice production. However, there are important differences between the two neighboring countries: firstly, because Vietnam has a much larger population of more than 90 million people and more advanced economy, demands on water are much higher, and irrigation is more developed to allow double cropping in many areas. Secondly, Vietnam has distinct weather systems in the northern and southern regions which cause wide variation in rainfall between different areas of the country. Water resources have been observed as key resources for development in Vietnam, which has over 2,300 rivers forming 15 major river basins (ADB, 2009). Although large areas of the country continue to rely on agriculture, Vietnam is rapidly urbanizing and has a high rate of economic growth, which will increase pressure on water resources across the country in future (ADB, 2009). For now, more than two thirds of Vietnam's population continue to live in rural areas, and agriculture is highly important for food security, socioeconomic development and poverty reduction. Because of the large seasonal variations between different regions, Vietnam experiences high rainfall variability within and between seasons, and up to three quarters of annual runoff is generated within three to four months of the year (FAO, 2011). Variable rainfall can result in heavy flooding in the rainy season and extreme low flows in the dry season, for which storage capacity and flood management structures are limited. The high variation also means that although average total annual rainfall reaches almost 2m, Vietnam can still be considered water deficient, and competition over resources may hold back development and livelihood opportunities in the future (ADB, 2006). Another risk to water resources in Vietnam is that many of its main rivers, such as the Mekong, are transboundary, and “almost 60 percent of the total water resources are generated outside the country, making the country susceptible to decisions made about water resources in upstream countries” (FAO, 2011: 476). Referring to both urban and agricultural water uses, ADB states that “groundwater is being extracted at unsustainable rates” (2006: 2). Although over-exploitation of groundwater is ongoing and is causing local problems of subsidence and salinity intrusion, total renewable groundwater resources currently remain abundant. Groundwater is mainly extracted for urban water supplies, and surface water is withdrawn for irrigated agriculture (FAO, 2011).

Agriculture and particularly rice have been critical to the development of the Vietnamese economy, and to increase productivity and manage rainfall variability, the country has invested heavily in developing large-scale irrigation since the late 1970s. This investment resulted in more than 8,000 irrigation systems, more than 700 medium- to large-scale reservoirs and about 2,000 pumping stations by the end of the 1990s (Biltonen et al., 2003). The high rainfall variability means that “irrigated production is the backbone of Vietnam’s rice economy” and has enabled increases in both productivity and cropping intensity for rice (Biltonen et al., 2003: 8). Large-scale irrigation covered more than 4.5 million ha by 2005, just under 50% of the total potential irrigated area in the country (FAO, 2011). This has enabled Vietnam to become a top global exporter of rice, which has strongly contributed to socioeconomic development because of the large majority of the rural population depending on paddy rice production. As well as the large-scale irrigation infrastructure for paddy rice, Vietnam is also very active in aquaculture. More than 80% of surface water withdrawal nationally is for irrigation, and more than 10% is for aquaculture (normally using small freshwater ponds <0.1 ha), and these sectors are both still expanding, although urban and industrial water withdrawals are increasing much faster (ADB, 2009).

Vietnam's national irrigation network has become in serious need of renovation, and FAO observes that "although the potential for irrigation is large, upgrading the existing and constructing new irrigation systems requires a huge amount of capital" (2011: 501). During the period of centralised economic planning in Vietnam from the 1970s to 1980s, irrigation systems were cooperatively managed and "major achievements in irrigation and drainage have been gained at both the system level and farm level" (Doan et al., 1996: 365). Irrigation management was weakened by transferring away from cooperatives in the market reforms, which reduced the overall irrigated area because of damage to infrastructure, unstable water supply to downstream areas, higher costs and water shortages (Doan et al., 1996). The system has continued to deteriorate across the country because of weak management and dependence on state funding and international aid to keep functioning (ADB, 2009). Because irrigation management has mostly been top-down from the government, with little involvement of farmers, irrigation mainly supports paddy rice, which makes it difficult for farmers to diversify to other crops. Dry season water availability is also a cause of problems in many river basins, causing conflict over water resources, risks to survival of aquatic life and potential for future water shortages (ADB, 2009). Le and Jensen (2014) observe that a key problem in the efficiency of large-scale irrigation systems in Vietnam is that, even with investments in renovation and expansion, outlying areas of the systems are still not inadequately covered. Partly for this reason, "the performance in terms of actual irrigated area to design capacity is <70% in Vietnam" (2014: 223).

Irrigation investments often lack pro-poor perspective, by focusing on large-scale policy objectives that may not consider local conditions, resulting in management of water resources that does not fully respond to farmer needs (Biltonen et al. 2003). Biltonen et al. (2003) suggest that some of these issues can be solved by improving use of natural water storage, strengthening the organisation of on-farm water management, and focusing at the village level. Because of the wide coverage of irrigation, on-farm water management in Vietnam mostly refers to the division of management and responsibilities between irrigation at the farm level and the organisation in charge of the main irrigation supply. In some systems farmers draw water onto their land themselves, while in other systems this is managed by the irrigation supplier. Evidence suggests that management is more efficient when the farmers control over their own water use (Biltonen et al., 2003). Although annual water resources are sufficient for agriculture in Vietnam, lack of storage is observed to prevent efficient water management in irrigation systems to respond to oversupply and undersupply, due to "extremely uneven evaporation, rainfall and flow distribution" (Biltonen et al., 2003: 151). This may require investments in ponds, bunds and reservoirs, but in many cases these structures already exist though they are weakly managed or need renovations. Biltonen et al. therefore recommend pro-poor management of water infrastructure, and financing for investments in renovation and new infrastructure at different scales to manage oversupply and store water for use during periods of undersupply (2003). Farmers in outlying areas have also adapted to inefficient and incomplete irrigation coverage by building local pumping stations and increasing traditional basket or mechanical lift irrigation to transfer water from on-farm canals. Le and Jensen found that mechanical pumping succeeded in "improving the flexibility and reliability of on-farm irrigation without compromising yields", and also "enhances on-farm irrigation efficiency and water productivity by reusing drainage water at the on-farm level, by converting outflows to locally beneficial uses, and by reducing the rice field water requirement relative to current irrigation norms" (2014: 237).

Even though many farmers have adapted in these ways to improve irrigation efficiency, climate projections forecast large reductions in total runoff in the coming decades, requiring much more efficient management of Vietnam's water resources (FAO, 2011). Reducing total availability of surface water availability with climate change is taking place at the same time as increasing seasonal variations, droughts and flooding. This puts Vietnamese people at high risk of natural disasters and other climate change impacts, including extreme rainfall, typhoons, floods and sea level rise, because of the proportion of the population living on the coast and in floodplains, particularly in the Mekong Delta. ADB summarises three key challenges in Vietnam's water sector as follows: “(i) increasing competition for heavily committed freshwater resources; (ii) increasing pollution of rivers by industrial, municipal, and agricultural sources; (iii) increasingly severe and frequent natural disasters affecting a rising population living in disaster-prone areas” (2006: 2). To try to find solutions to these issues requires strengthening many aspects at the same time, including management institutions, investment in water infrastructure and community participation in managing water resources, disaster response, and planning for how to protect communities from disasters in future (ADB, 2009; FAO, 2011). Although they are on a different scale and with different local conditions, the issues facing Laos are very similar to the issues facing Vietnam, and there are important lessons that can be shared between the two countries.

Thailand

Like Vietnam, Thailand borders Laos while also being similar to Vietnam in its latitude range, with large variation between different monsoonal zones. The northeast of Thailand in particular faces very similar climate change risks to Laos, as well as having similar livelihoods and farming conditions. Since 1960 the government of Thailand promoted export-oriented cash crop monoculture practice, and after two decades the problems (e.g. effects on soil productivity from fertiliser application etc) from intensive agriculture started to appear in the 1980s. Rice has been one of the most important exports of Thailand since the second half of the 19th century. Thailand first exported rice to China, and since the late 19th century exports had gradually shifted to other neighboring countries such as Malaysia, Indonesia, Singapore and Philippines. The export volume of Thai rice increased rapidly from one to two million tons of milled rice per year to more than four million tons per year, which accounts for around 40% of the world's rice trade (Yasuyuki and Pradip, 1995), while sustainable agriculture was later promoted to transfer from monoculture to multi-crops or mixed faming (Suksri et al, 2008). Groundwater is a critical source for all countries of the Mekong river basin for drinking, industry and agriculture, which includes Thailand (Pokhrel et al, 2018), although the overflow of surface water from the riverbank during the rainy season has commonly not been efficiently utilised.

Thailand's population predictions suggest an increase to over 80 million people by 2030, an expansion that will increase pressure on groundwater while adding further dependence on diverting river water flow and quality. Overall, the concerns of the governments of the lower basin focus on water quantities and flows, while many NGO's and local groups are troubled by water fluctuations and river bank collapse (MRC, 2010), as well as the impacts of mainstream hydropower development. This issue has become a hot topic of research and media reporting, with many publications touching upon environmental, ecological and hydrological consequences, though on the other hand, how agriculture is affected by changing water supply conditions has not been highlighted as much yet in Thailand (Fredén, 2011). Therefore, rainwater harvesting should also be considered in Thailand in terms of the location and benefits of harvesting rainwater for use in changing conditions caused by different factors.

CHAPTER III
METHODOLOGY

3.1 Description of the Study Area

The study focused on the three villages of Mouangkhai, Thouat and Taleo in Champhone District of Savannakhet Province, Laos (Figure 3). The three villages are located on the low-lying floodplain in upstream, middle and downstream areas of the Xe Champhone river, and are characterised by high flood vulnerability (Hazarika et al., 2008). The elevation of the area is 94 to 227m above sea level, and features a wide area of paddy land, swamps and limited areas of forest. The total area of Champhone District is 102,984 ha, with agriculture covering 93.61% of the area. Activities on climate change adaptation have been introduced in some villages of Champhone district, such as capacity building, training (e.g. improvement of high rice production and quality, hybrid varieties and frog breeding), extension of a soil irrigation cannel by 1,000 m, which covers 76 ha of rice fields for use in dry season, and soil analysis. However, the activities were stopped after the end of the project because of high budget requirements (MRC, 2014a). This highlights the need for adaptive measures that reflect local budget and capacity, as is the basis of the present study.

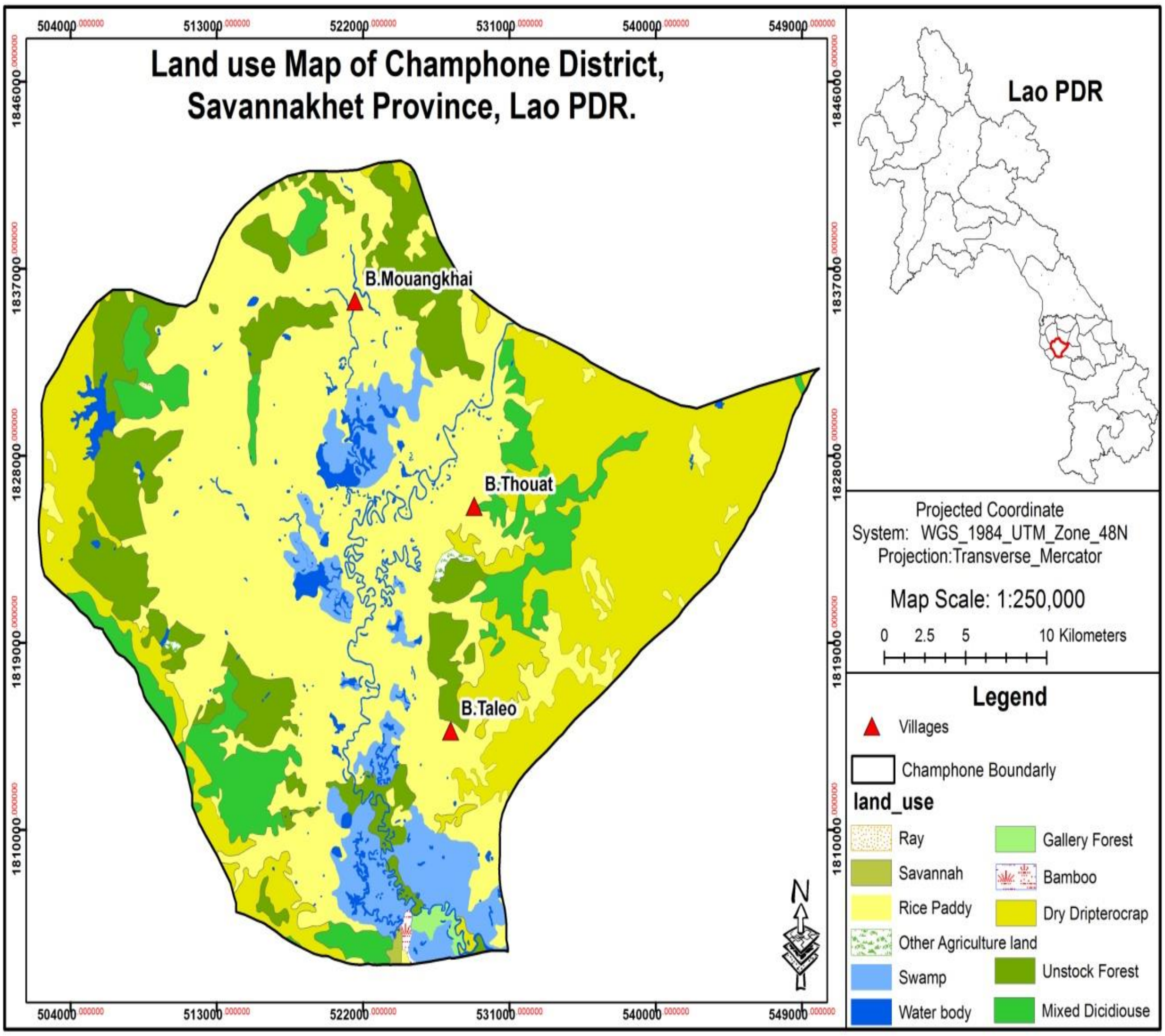


Figure 3. Map of Study Areas in Champhone District of Savannakhet Province, Lao PDR.

3.2 Selection Criteria for Study Sites

Champhone District, Savannakhet Province was chosen as the study site for the research for the following reasons: 1) it is a key agricultural area of Savannakhet Province, especially in terms of rice production; 2) the Xe Champhone ("Xe" meaning sub-river) is the main water source utilised by agriculture in the district; and 3) rice fields in the district are vulnerable to impacts whenever flooding occurs. The present study was conducted in three villages of 15 villages that had previously been heavily affected by flood, located along the Xe Champhone riverbank (Figure 4), an area which contains both rice fields and residential areas (Sengtianthr, 2011).

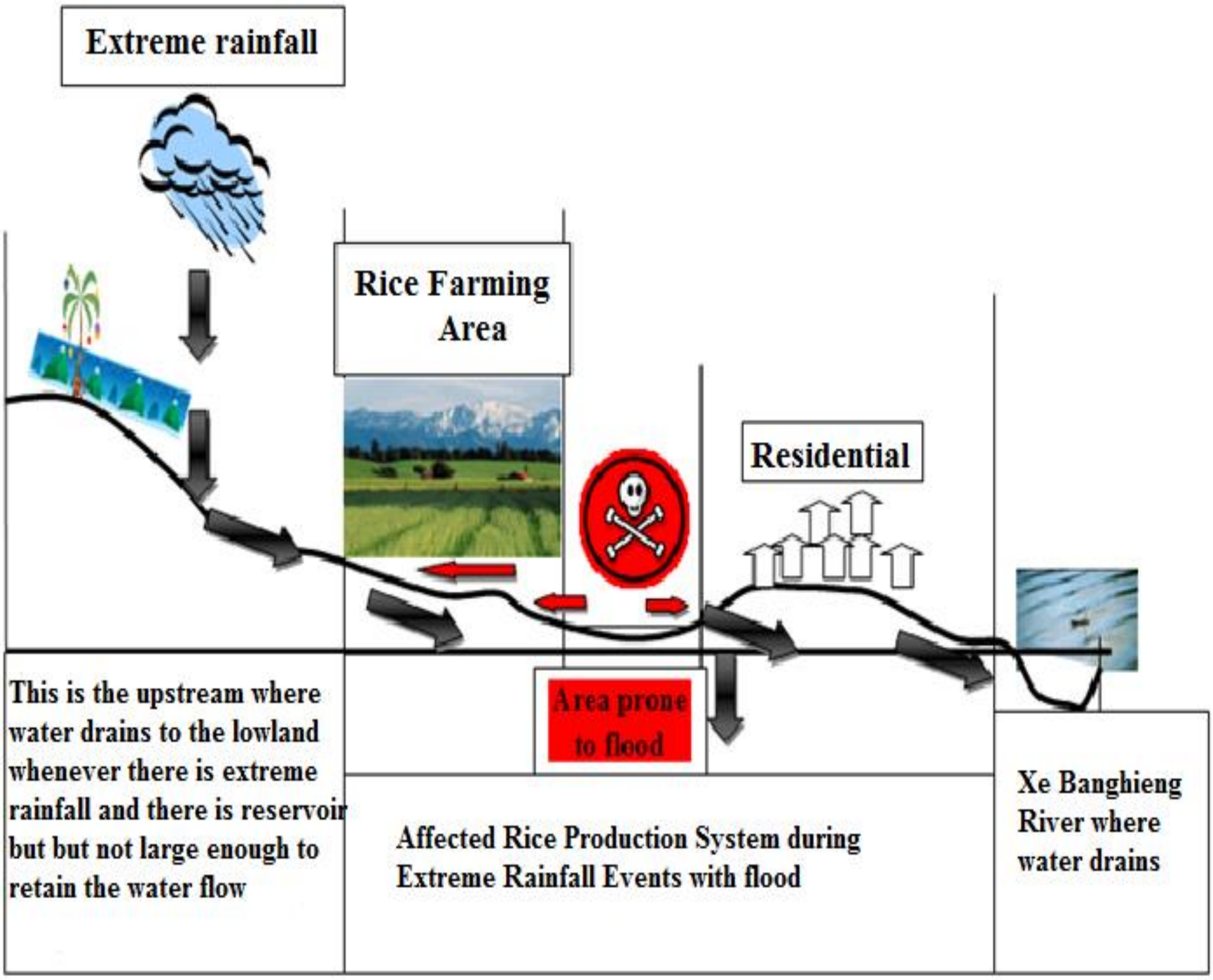


Figure 4. Transect of Champhone District showing the flood affected area during extreme rainfall.

3.3. Analytical Framework

The analytical framework of the study applied maps generated by GIS and rainfall data calculations to show variations in the water level and extended flow from the Xe Champhone river. Farmer experiences provided data on the flooding of rice farming and household areas. Socio-economic survey data identified and analyzed the proneness of the community to flooding in terms of rice farming and crop yields. The indicators of adaptive capacity (water availability, rice storage and irrigation systems) and proneness to flooding show the vulnerability of the community to flooding in rainy season, while lack of water for crops indicated high vulnerability to drought in the dry season. This analytical approach helped to identify community adaptation options based on water harvesting, to ensure timely response and support the resilience of households and local rice security (Figure 5).

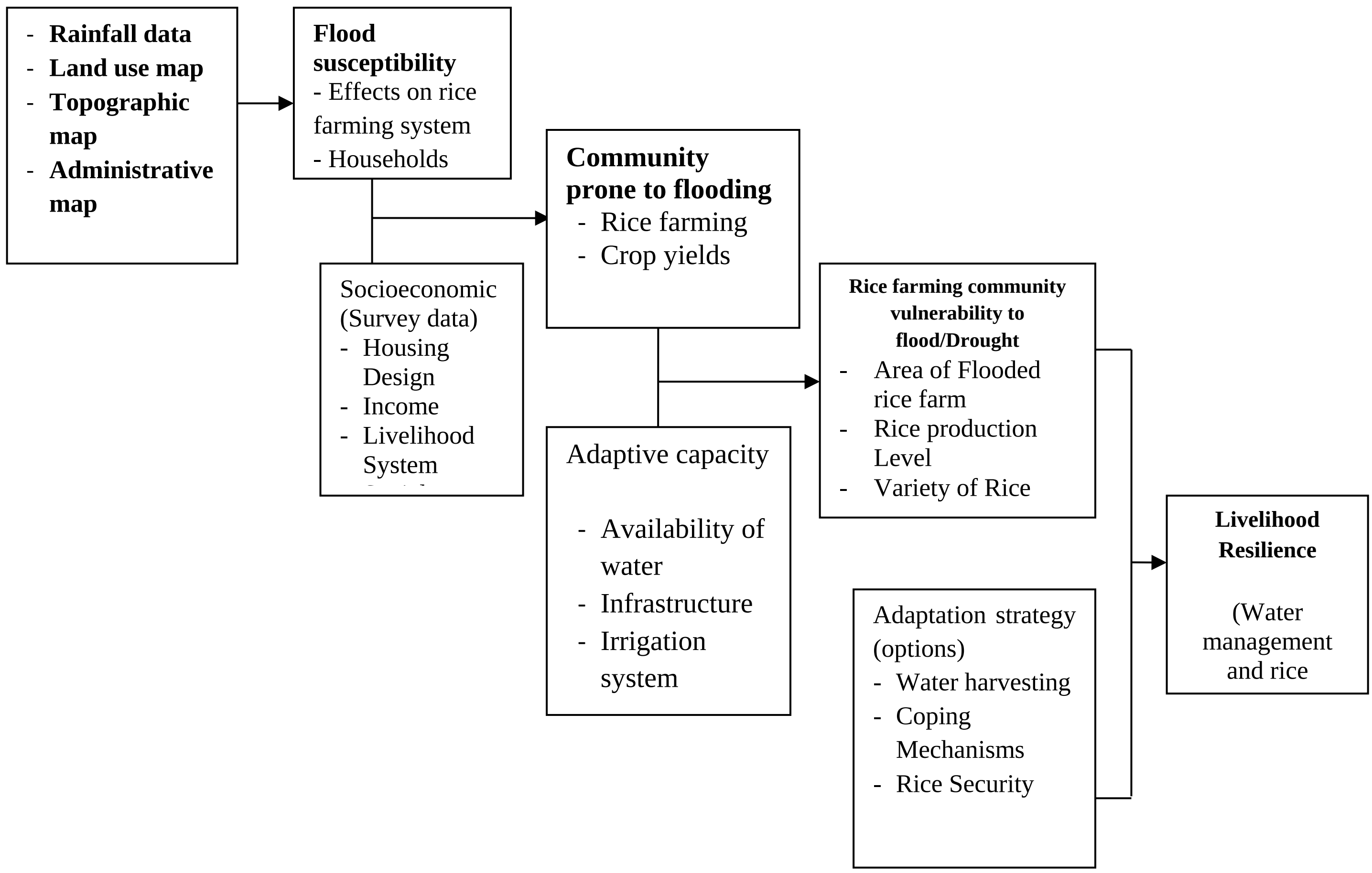


Figure 5. Analytical Framework of the Study.

3.4 Data Collection

Interviews were conducted using a structured questionnaire (see Appendix.1) related to the key research issues. The respondents of the household survey were from the 3 villages of Muangkhai, Thout and Taleo in areas near and alongside the riverbanks. The respondents of the study were listed and selected through proportional stratified random sampling, with the villages as strata. Taking into account the limitations of time, funds, distance and resources, the total sample size was computed by using Slovin's formula (Sevilla et al., 1984 as cited by Baltazar, 2003):

$$n = \frac{N}{1+Ne^2}$$

Where n = Sample size

N = Population size

e = Desired marginal error

Calculation for the present study:

n = 253/1+ (253*0.025)

n = 253/1.63

n = 154

After the total sampling frame was determined for the three villages, the sample size per village was calculated as below:

$$n_i = \frac{nN_i}{N}$$

n_i = Sample size in each village (i=1, 2, 3)

n = Total sample size for three villages

N = Total number of households in three villages

N_i = Number of households in each village (i= 1, 2, 3)

Respondents of the household survey were interviewed based on the elevation of the area. It should be noted, however, that these locations were not the first priority in terms of being affected by flooding, but were considered because of their locations near the Xe Champhone and resulting vulnerability to flood damage. Figure 6 shows the flow diagram of data collection until processing.

Table 1. Sample size in 3 villages.

No	Village name	Number of households (Ni)	Calculation	Sample
1	Muangkhay	33	33*154/253	20
2	Thouat	157	157*154/253	96
3	Taleo	63	63*154/253	38
Total		253		154

3.5 Respondents of the Study

Survey interviews were conducted based on the priority areas affected by flooding for sampling from the 3 villages. Respondents were considered because of their agriculture land near the Xe Champhone being vulnerable to damage from the flooding. To characterise social and economic drivers of flood vulnerability in the study locations, household interviews were conducted during the dry season based on the availability of farmers, using a structured questionnaire with respondents located near and along the riverbanks in the 3 villages of Mouangkhai, Thouat and Taleo.

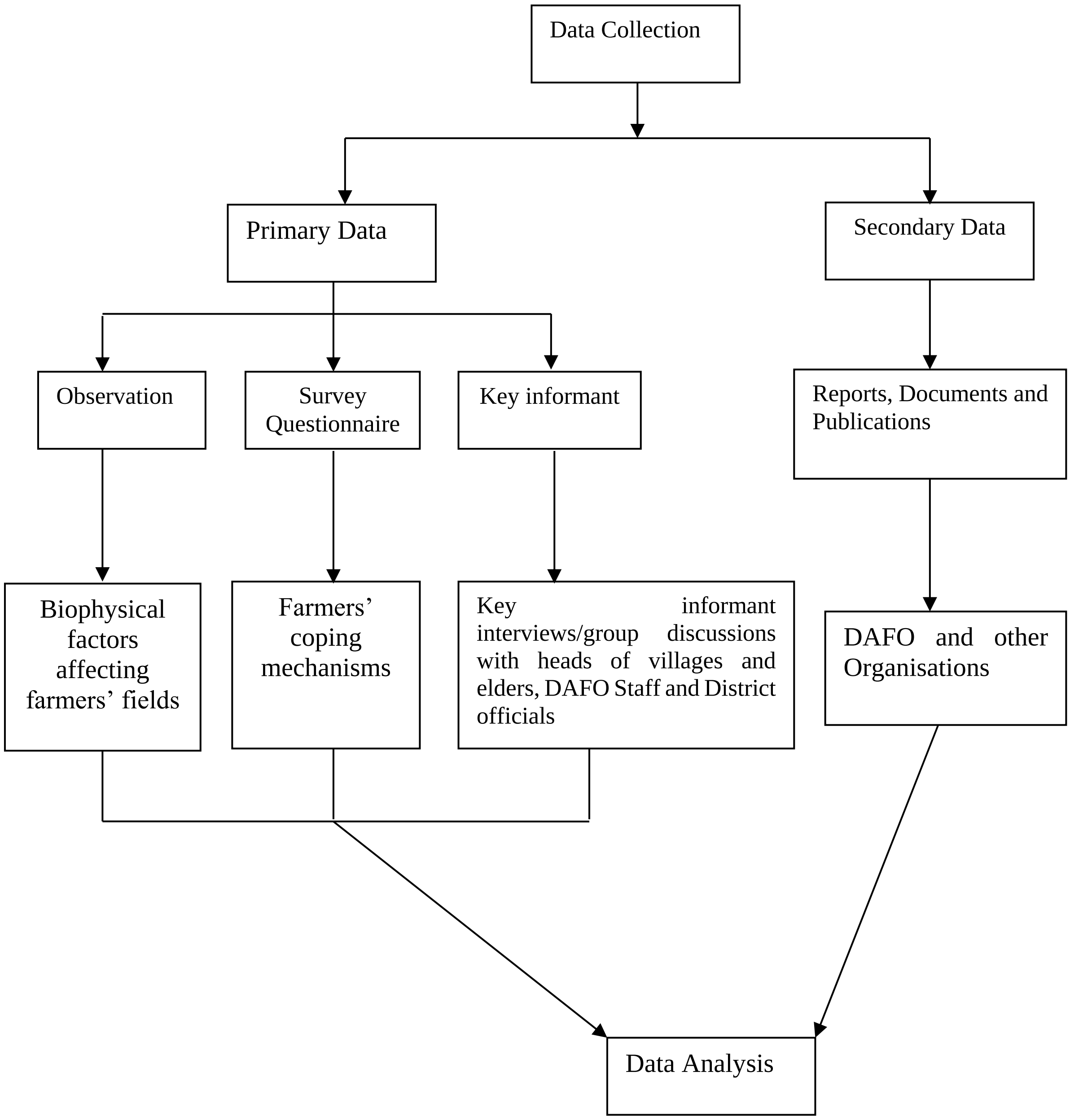


Figure 6. Process of primary and secondary data collection.

3.6 Household Interviews

Primary data including river characterisation were collected in the study areas through direct interviews with the respondents and group discussions in the presence of key informants (Figure 7).

Figure 7. Interviews with respondents during dry season at the study sites in Champhone district, Lao PDR.

3.7 Key Informant Interviews

Some officials in the district and villages were carefully selected as key informants (Figure 8). These key informants are the main practitioners in the rice production process, land use, and in terms of the flood scenarios in those particular areas. They are familiar with the details of all flood related matters in the respective villages. At the national level, the key resource persons were those who carry out capacity building in the pilot areas - policy makers, chairpersons, and those facilitating institutional development. At the local levels, key informants were the actors leading the implementation of activities within the community. Key informant interviews were mainly carried out by phone and by emails consisting of several questions and sometimes further clarifications on ongoing and changing activities in the field.

3.8 Focus Group Discussions

Focus Group Discussions (FGDs) were conducted at the local level in the 3 villages of Mouangkhai, Thouat and Taleo. This has been proven a suitable method to discuss issues at ground level, such as in capturing actual implementation and status at the local level (Figure 8), with follow-up group FGDs after the rainy season to understand issues faced by the farmers through the planting cycle.

Focus group discussions are important forms of qualitative methodology to collect data from a group of individuals and discuss and comment based on personal knowledge on the specific issues of the research. They can be used to explore a range of opinions and views on a topic of interest. In the present study, focus group discussions were used for the in-depth interviews by providing information based on the interaction through discursive short debates between different actors on the different issues raised.

Figure 8. Activities at the end of the rainy season at the study sites in Champhone district, Lao PDR.

3.9 Secondary data

Documents were also sourced from the concerned institutions of the Lao government. Historical weather data for 1995-2015 were obtained from the Provincial Meteorology Station Office (PMS) of Savannakhet. River information of the district came from the Department of Natural Resources and Environment in the provincial capital of Savannakhet. Water discharge was analyzed using the Bradshaw Model (Bradshaw et al., 1978).

3.10 Possibility Distribution

Historic rainfall data provided by the meteorology division in Savannakhet for 1995-2015 were used to calculate the runoff between rainy season and dry season to determine the water balance during the year. Gumbel's extreme value distribution method was used for probability distribution for each selected data series. Hydrological studies can be expressed by the following equation of the hydrologic frequency analysis (Palaka et al., 2016):

The rainfall (P_T) corresponding of a given return period (T) using Gumbel's Distribution:

$$P_T = \sigma + K.S \tag{1}$$

Where : σ $Average\ Anunual\ Daily\ Maximum\ Rainfall$

S Standard Deviation of $Anunual\ Daily\ Maximum\ Rainfall$

K Frequency Factor give by :

$$K = -\frac{\sqrt{6}}{\pi}[0.5772+\ln[\ln[\frac{T}{T-1}]] \tag{2}$$

Then the intensity of rainfall (I_t) is obtained for the return period T from equation:

$$I_T = \frac{P_t}{T_d} \tag{3}$$

Where T_d is duration in hour

The frequency of rainfall is usually defined by reference to the annual maximum series, which consists of largest values observed in each year.

3.11 Suitability of Water harvesting Methods

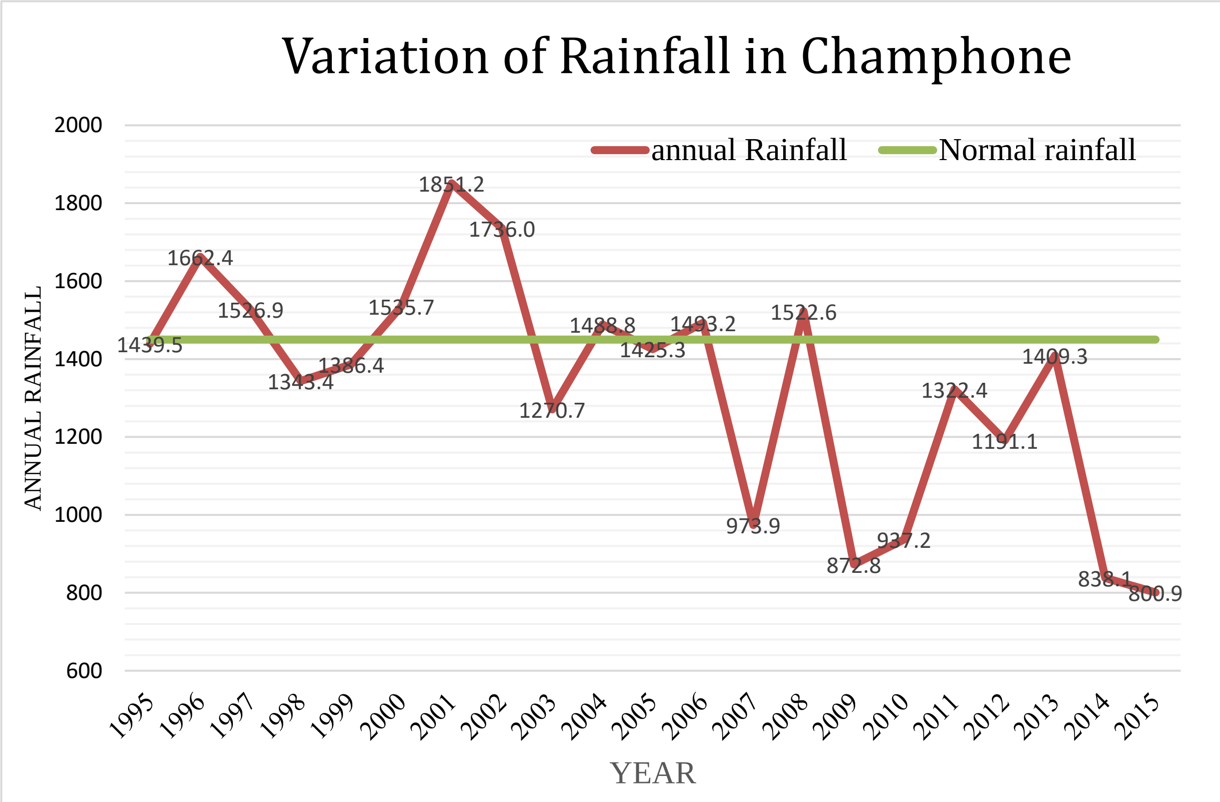
The suitability of methods for water harvesting were determined based on the results of survey interviews combined with key informant and group discussions, using SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) to classify their adaptive capacity towards water management and benefits for resilient agricultural livelihood practices.

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Localised impacts of climate change in communities along the Xe Champhone River

4.1.1 Community exposure to variable rainfall conditions

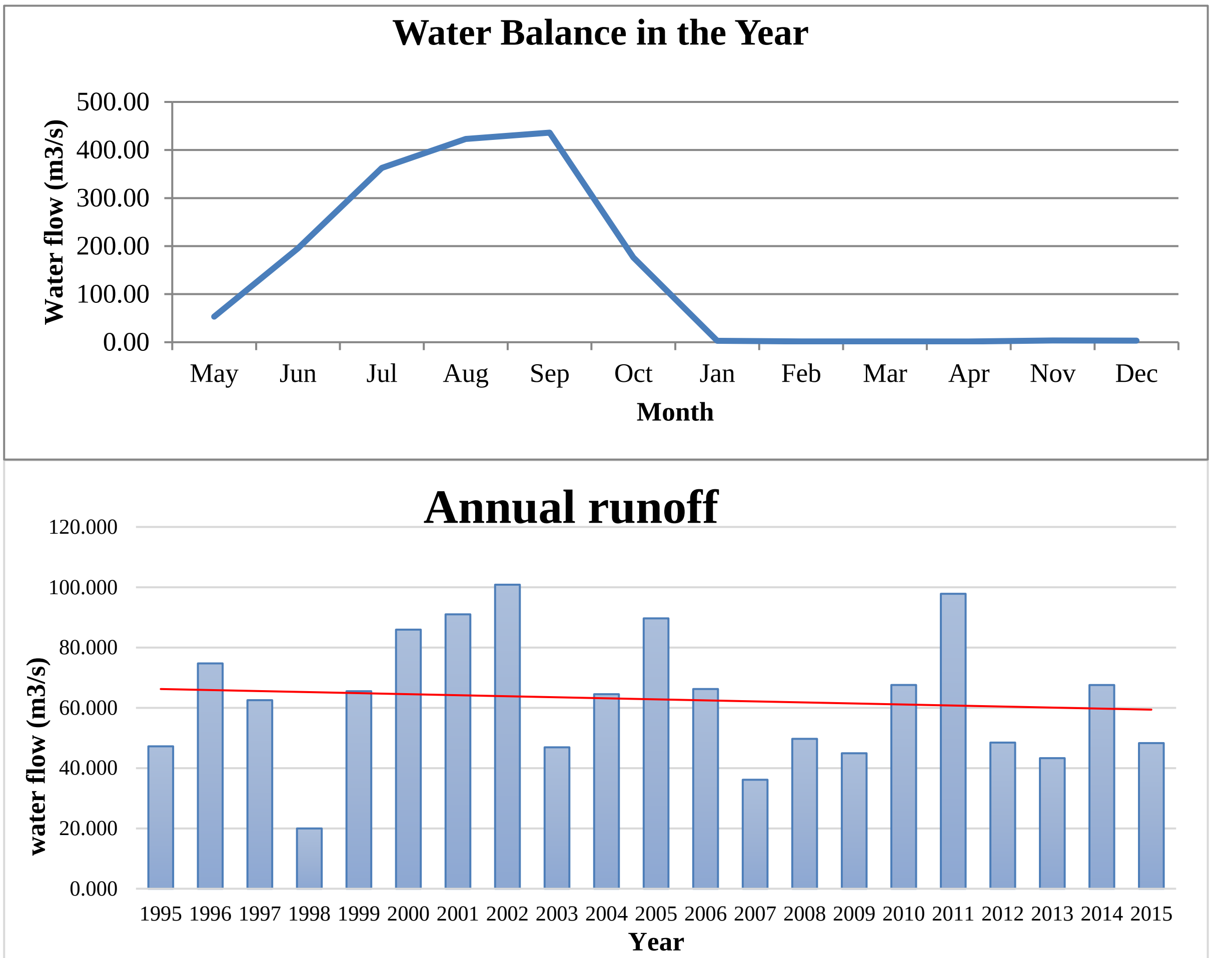
Flood records of the Xe Champhone river (Appendix 3) show the frequency of flooding during the rainy season, often peaking in the statistics during August-September, while in the dry season from December to May the area can become very dry. Records also show how often near-flood conditions are reached in the Xe Champhone, highlighting the vulnerability of local farmers. According to a key informant interview with the head of the Provincial Department of Environment and Natural Resources, the overall observed trend is towards higher frequency of extreme events and increased rainfall intensity, while the total rainfall and number of wet days has decreased. Figure 9 shows a downward trend in the frequency of maximum 24-hour rainfall above 150 mm/day after 2003, but higher overall variation compared with beforehand. IPCC research projects an increase in extreme rainfall events (IPCC, 2014), which could generate further flooding at the study sites. Changes in rainfall in this region strongly relate to the El Niño and La Niña phenomena. El Niño rainfall is lower (the abnormal rainfall of less than 117 mm), rainy days are fewer, the rainy season begins late and is shorter, and droughts are more frequent. The opposite occurs during La Nina: rainfall is higher (the abnormal value is 339 mm); the rainy season begins earlier and lasts longer.



Source: Department of Natural Resource and Environment in Savannakhet, 2016

Figure 9. Variation of Annual Rainfall in Champhone district from 1995-2015.

The higher overall variation rainfall (Figure 9), in combination with the high maximum daily water height of the river, suggests occurrence of flooding. Similar observations have frequently occurred according to meteorological records from 1988 to 2015, which also indicate the high likelihood of flooding in the months of July and August (see Appendix 3). This would initially bring irrigation water for rice farms along the river on the floodplain. This is supported by the difference of discharge amount during the dry season and rainy season (Figure 10), showing the water balance in Champhone station: while the minimum runoff is very low in dry season ($Q = 2.5\ m^3/sec$), the maximum runoff is high in rainy season ($Q = 274\ m^3/sec$). Annual runoff has meanwhile been decreasing on average from 1995-2015.

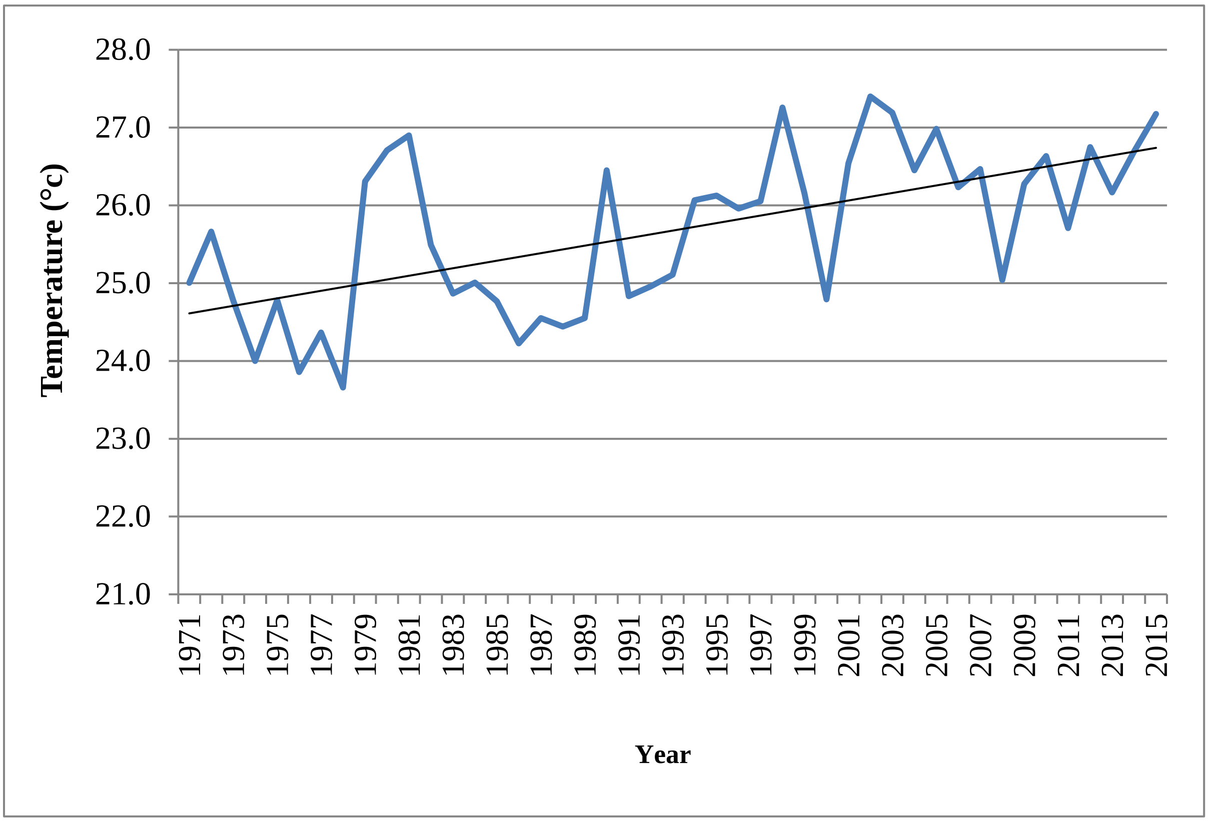


Source: Department of Natural Resources and Environment in Savannakhet, 2016.

Figure 10. Average water balance during the year and annual runoff in Champhone District from 1995-2015.

4.1.2 Temperature

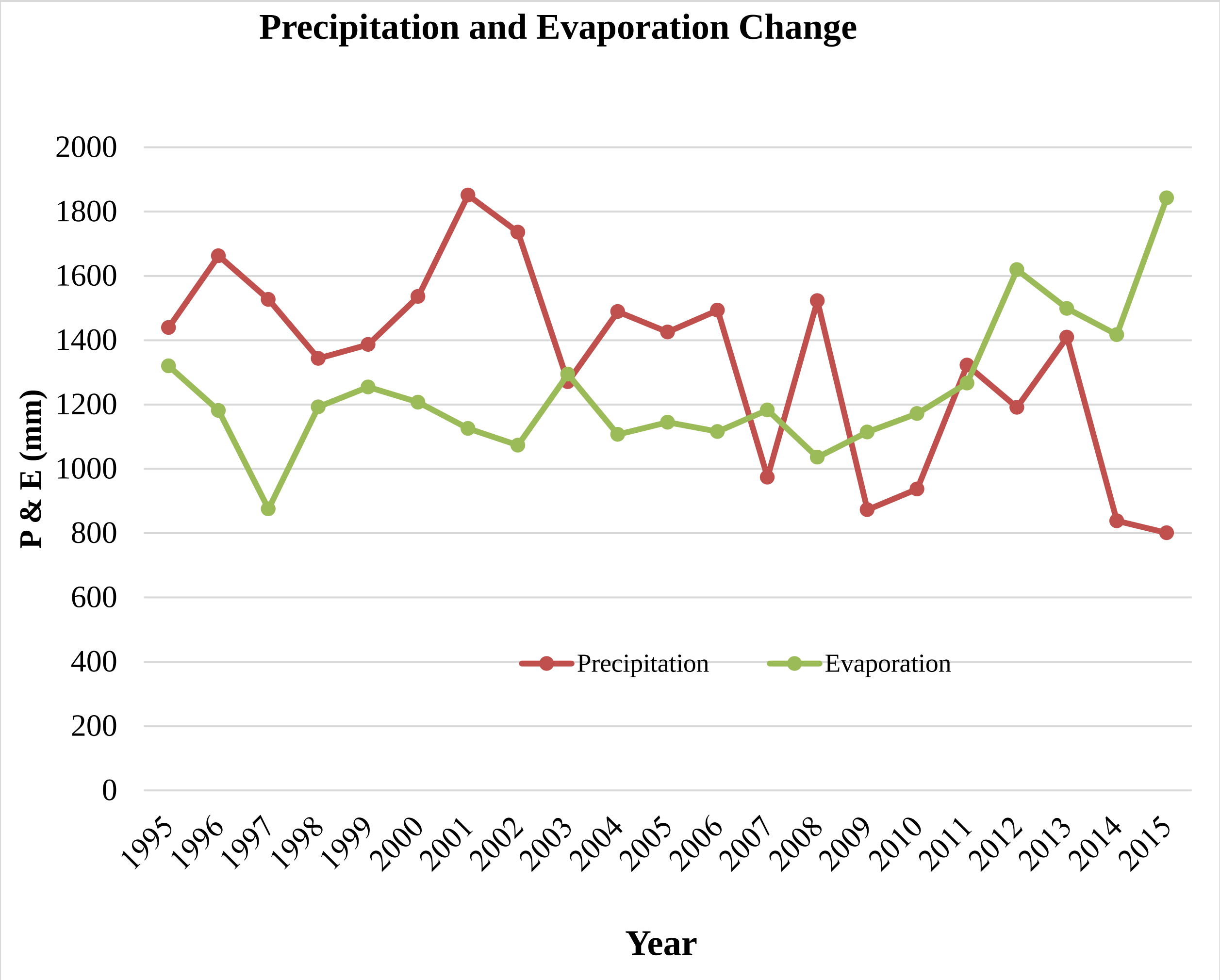
Figure 11 illustrates the change in temperature relative to 1971-2015 average temperatures. (Source: DNRAE in Savannaket, 2016). Data show unstable temperatures year-on year, with an overall increasing trend towards. The IPCC has predicted that by the end of 21st century, the average global temperature will increase by 2-4 degree Celsius (°c), leading to an increase in the average sea level by 0.18-0.59 m that could bring increased floods.



Source: Department of Natural Resource and Environment in Savannakhet, 2016.

Figure 11. Average annual temperature from 1971-2015 in Savannakhet Province.

Combined with the increasing temperature, figure 12 Shows precipitation and evaporation have also changed, especially since 2007 to the present, after which, although there is high variation, precipitation has generally fallen below evaporation. This aligns with global observations of the changing patterns of precipitation towards increases in heavy rains, which are generally found to be occurring in most locations, although mean precipitation is not increasing. Much of the increase in heavy rains occurred during the last 3 decades, along with increasing occurrences of flooding (Trenberth, 2011). The local and regional changes in precipitation largely depend on variations in atmospheric circulation (Trenberth, 2011). The distribution and timing of floods and droughts is most profoundly affected by the cycle of El Niño events, particularly in the tropics and over much of the mid-latitudes of Pacific-rim countries (Diaz & Markgraf 2000). Figure 12 shows that the high variation and downward trend in precipitation and rising trend in evaporation indicate lack of predictable water supply and vulnerability to extreme events.



Source: Department of Natural Resource and Environment in Savannakhet, 2016.

Figure 12. Average Annual Precipitation and Evaporation in Champhone district from 1995 – 2015.

4.1.3 Probability Distribution

Figure 13 and table 2 show rainfall intensity against estimated duration for different flood return periods. The pattern is closely similar in each case, with short term high-intensity rainfall (representing an extreme weather event) reducing to longer term normal levels. Climate studies suggest that this pattern will increase in frequency in future. The flood assessment of 10, 20 and 50-year return periods in Champhone district found a large area to be highly vulnerable to flooding at depths of greater than 6m (Hazaraki et al., 2008).

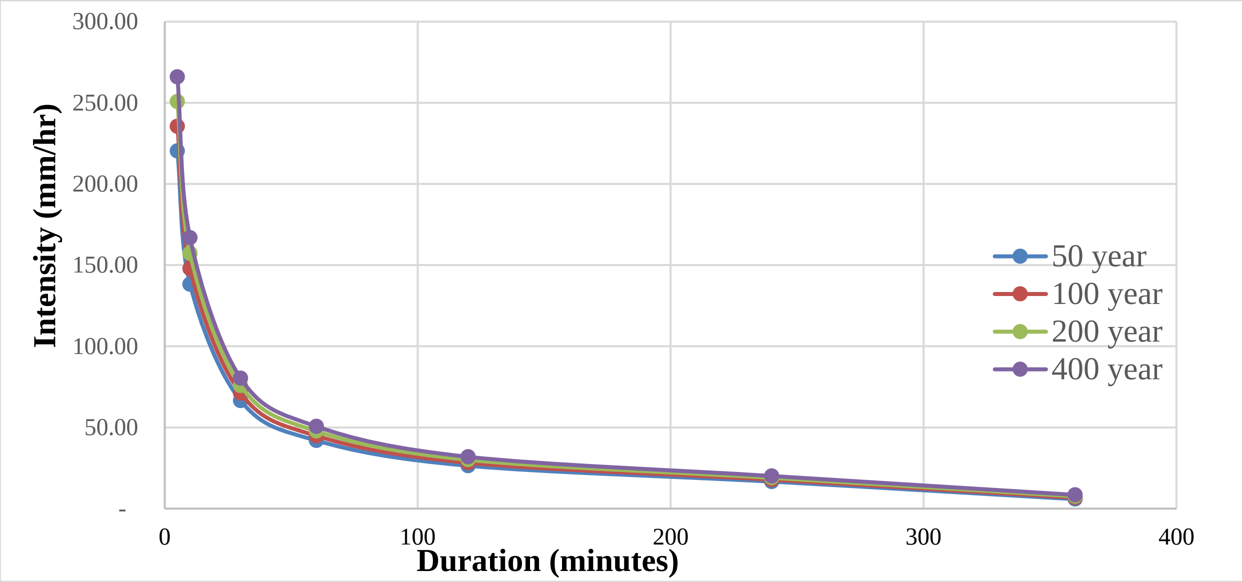


Figure 13. Rainfall intensity estimations for 50, 100, 200, and 400 year return periods.

Table 2. Rainfall intensity estimations for 50, 100, 200, and 400 year return periods.

Return period (years)	**x**	**y**	**Intensity** $i = x*(t_d)^{-y}$	**correlation coefficient, R**	R^2
50	1,442	0.694	$I = 850.9* t_d^{-0.76}$	0.998	0.9962
100	1,604	0.691	$I = 886.1* t_d^{-0.75}$	0.998	0.997
200	1,764	0.688	$I = 923.1* t_d^{-0.74}$	0.999	0.9976
400	961	0.743	$I = 961.49* t_d^{-0.74}$	0.987	0.975

4.2 Biophysical Sensitivity

Based on key informant interviews, the areas along the river are commonly flooded when river overflows its banks (Figure 14, 15, 16). However the flood water has not yet reached the residential areas of the three villages because they are located at higher ground and are far from the riverbank. The flood water damages roads and bridges in the villages. Moreover, access to the market to buy their basic needs is difficult.

The figure 14 shows the flood plain area which affected lowland rice in Taleo village during the rainy season in 2017. According to one key informant, villagers did not know about weather forecast or frequency of extreme rainfall so had no possibility to reduce the flood impacts and damage to rice fields. The key informant expressed concern about rice insecurity for his family during the dry season in that year.

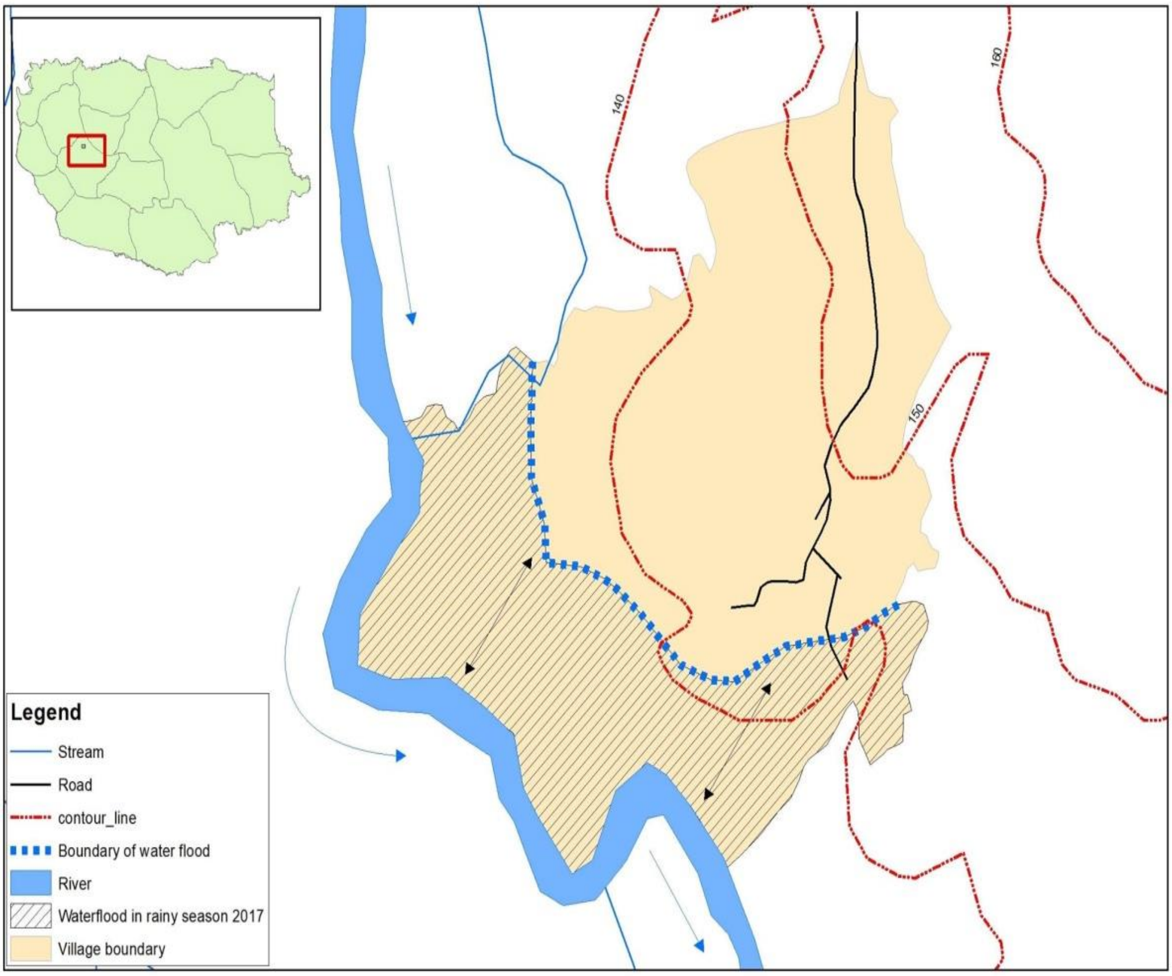


Figure 14. Flood area during rainy season at Muangkhai Village in 2017.

Figure 15 shows the flood plain area affecting lowland rice in Thouat village during the rainy season in 2017. One of the affected farmers said that “I could not predict when rainfall will come, I just grow base on the water supply or when there is enough rain to start growing, so after the first flood I tried replanting already, but when the rain came again it destroyed all of my field.” The informant expressed the same concern as those affected in Taleo about rice insecurity for his family during dry season. However, in this case the farmer could grow a dry season crop due to the nearby irrigation canal, though this covered just 1/3 of his field, and the respondent was concerned over how well the rice would grow in the next season.

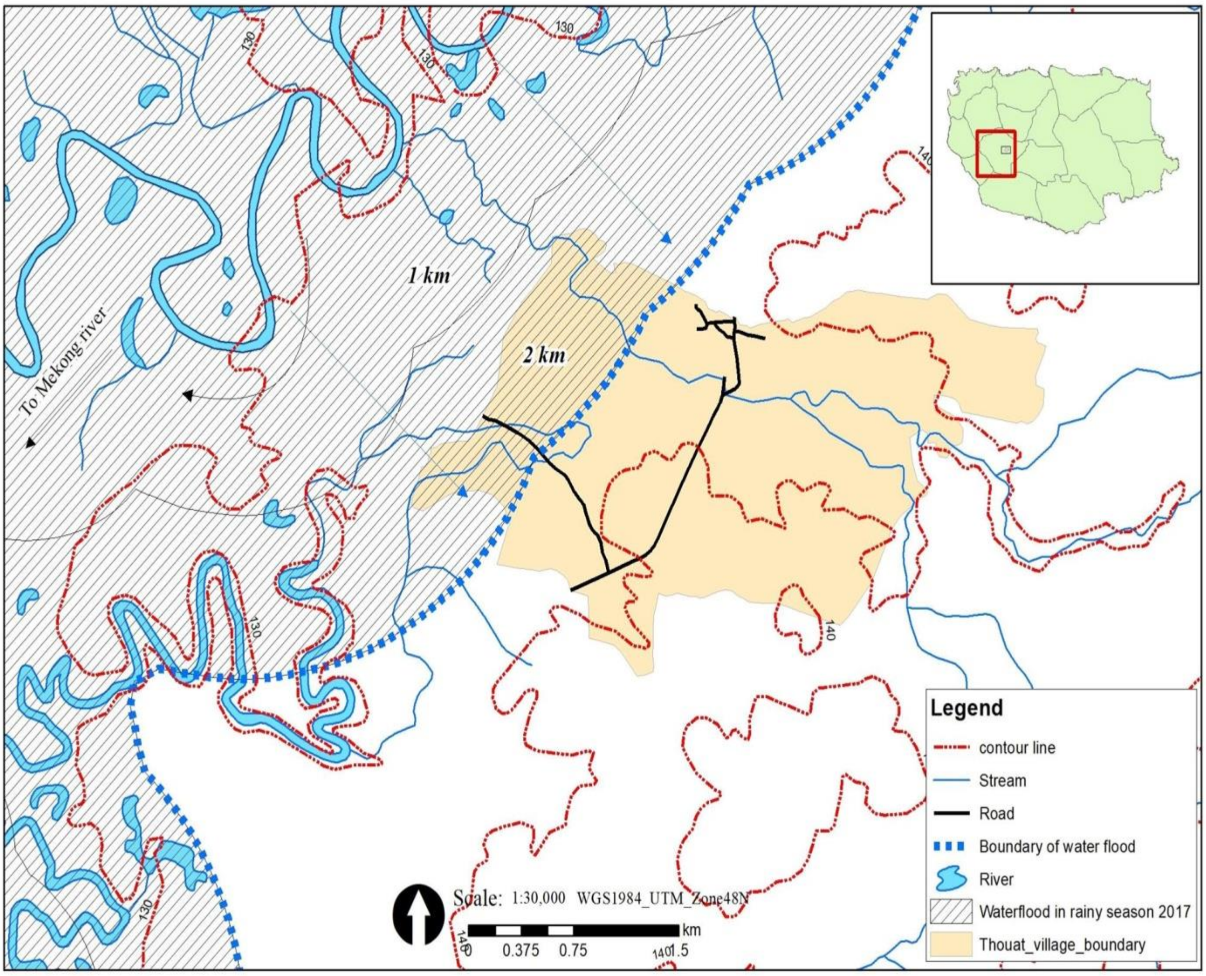


Figure 15. Flood area during rainy season at Thouat Village in 2017.

Figure 16 shows the flood plain area that affected lowland rice in Taleo village during the rainy season in 2017. During the group discussion in the dry season, farmers reported that flooding in this year was longer and they had received more extreme rainfall, so were unable to plant rice in the flood plain. Farmers expressed similar concerns to those in Muangkhai and Thouat about rice insecurity during the dry season, and were unable to grow dry season rice or other crops due to lack of water.

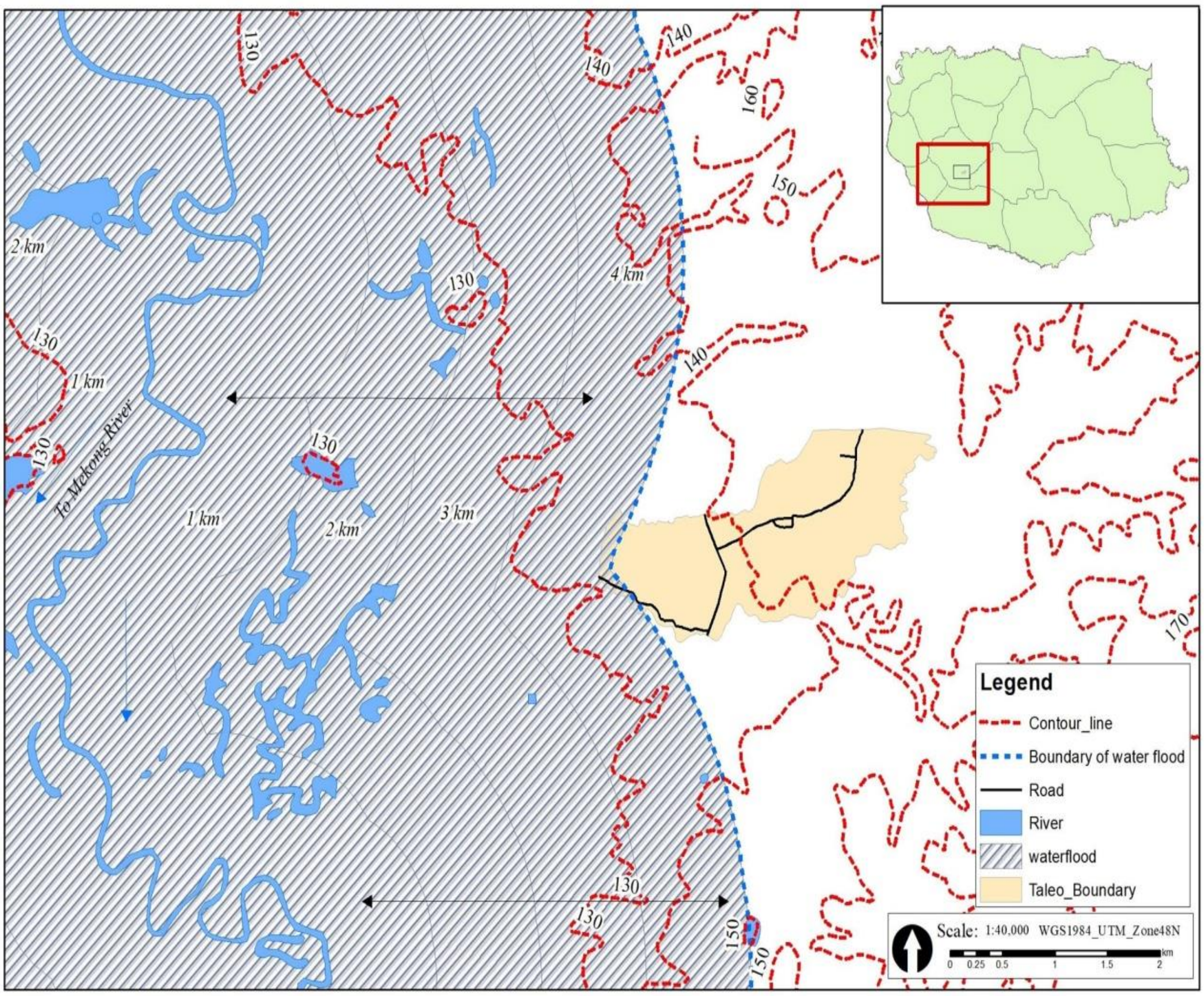


Figure 16. Flood area during rainy season at Taleo Village in 2017.

Rice Cropping Period The majority of respondents did not want to change their rice cropping period unless an irrigation project is developed to enable a dry season crop and reduce flood damages of their crop (Table 3). With short maturing varieties and an irrigation project, the communities can reduce if not avoid flood damages.

Table 3. Rice planting calendar in the rainy and dry season at the study sites.

ACTIVITIES	MONTHS											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Plow rice fields												
Sow seeds												
Transplant rice												
Panic harvest if poor rainfall conditions (flood/drought)												
Harvest												
Potential Drought Period												

Rainy Season
Dry Season
Heavy Rain (Flood Period)
Lack of water for agriculture

4.3 Community adaptive capacity against climate variability

4.3.1 Vulnerability of Lowland Rice

Wet season rice production in the study sites is very vulnerable to flooding. The communities have limited social, economic, and biophysical adaptive capacity with severe flooding and as a consequence, they need to secure rice from other areas. They have a limited livelihood system with the majority having only 1 ha to farm. Members of the family find themselves needing to search for jobs outside the village and as far as Thailand to support the farm household, and skills are often inadequate as the majority have lower educational levels and therefore access to low income work. The projected climate conditions would make them more vulnerable, with increasing population (Figure 17).

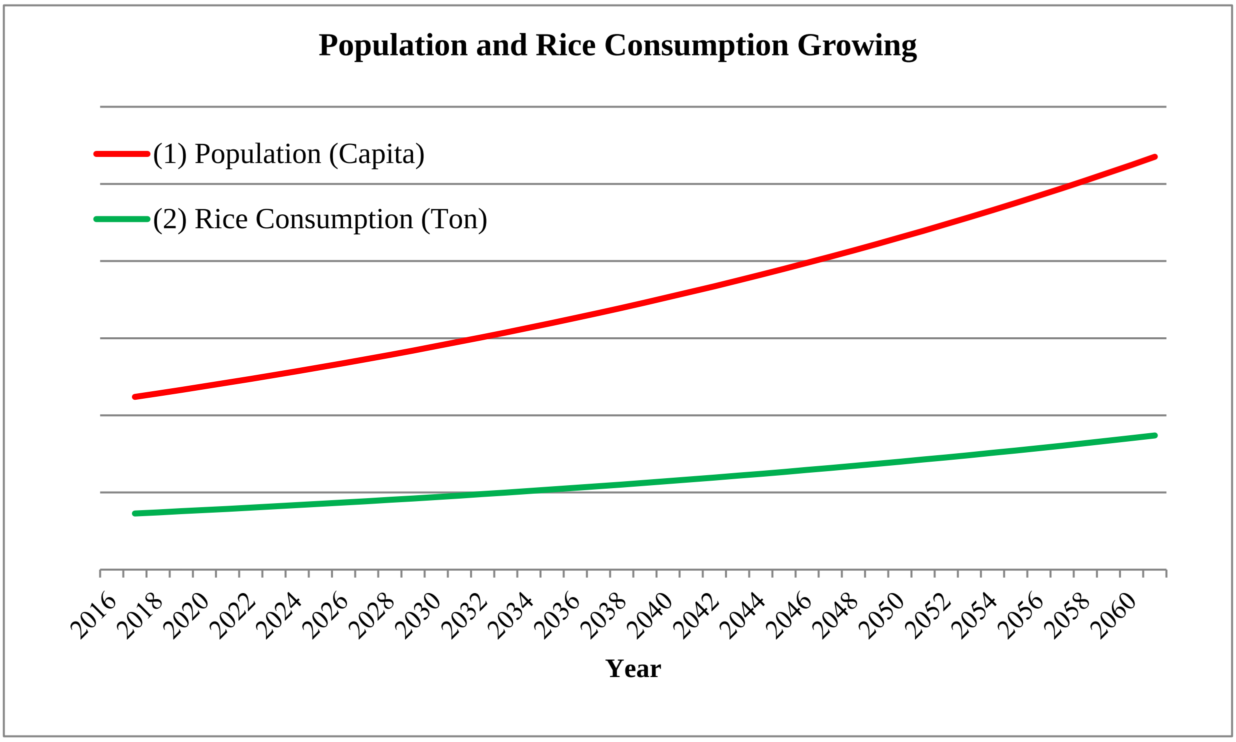


Figure 17. Projected increase in rice consumption with population growth.

4.3.2 Rice Production Projection

Table 4 presents estimated rice production and consumption in Champhone district from 2016 to 2090, showing increasing rice consumption with time. As shown above, rice production is not stable because of flood and drought. Based on interviews, the respondents indicated that they have enough rice for consumption and can sell the surplus if there will be no climate disturbance, especially extreme rainfall which causes flood. With flooded conditions, they cannot achieve a good harvest and start to incur losses. According to the Department of Agriculture and Forestry, in Savannakhet province with normal flooding, estimated loss in rice production due to flooding is 15%. This means that people will need to buy rice from outside for their consumption with severe flooding, as happens when there are losses in rice production. According to the Department of Agriculture and Forestry, this scenario will impact on rice sufficiency (Figure 18). For example, in 2035, the population of about 163,119 would need 53,013.72 tons of rice with an estimated maximum in one season production of 77,103 tons without flood. But with flooded conditions, a 32% loss in rice production would amount to 52,430 tons, which means that they would need to import 24,673 tons of rice. Moreover, with the roads underwater, it is very difficult to transport and buy basic goods in the village.

Table 4. Projection of rice production.

Year	(1) Population	(2) Rice Consumption (Ton)	WITHOUT FLOODING (3) Rice Production (Ton)	(4) Available Rice for cash (Ton)	(5) Income from Rice (USD)	(6) Income per Month (USD)	WITH FLOODING (7) Rice Production	(8) Rice Deficit (Ton)
2016	111970	36390.3	77,103.0	40,712.8	10,178.2	848.182	52,430.0	16,039.8
2017	114209	37118.1	77,103.0	39,984.9	9,996.2	833.020	52,430.0	15,312.0
2018	116494	37860.4	77,103.0	39,242.6	9,810.6	817.554	52,430.0	14,569.6
2019	118823	38617.6	77,103.0	38,485.4	9,621.3	801.779	52,430.0	13,812.4
2020	121200	39390.0	77,103.0	37,713.0	9,428.3	785.688	52,430.0	13,040.1
2025	133815	43489.7	77,103.0	33,613.3	8,403.3	700.277	52,430.0	8,940.3
2030	147742	48016.2	77,103.0	29,086.8	7,271.7	605.976	52,430.0	4,413.9
2034	159921	51974.2	77,103.0	25,128.8	6,282.2	523.516	52,430.0	455.8
2035	163119	53013.7	77,103.0	24,089.3	6,022.3	501.860	52,430.0	(583.7)
2040	180097	58531.4	77,103.0	18,571.6	4,642.9	386.908	52,430.0	(6,101.4)
2045	198841	64623.4	77,103.0	12,479.6	3,119.9	259.991	52,430.0	(12,193.4)
2050	219537	71349.5	77,103.0	5,753.5	1,438.4	119.865	52,430.0	(18,919.5)
2053	232974	75716.7	77,103.0	1,386.3	346.6	28.882	52,430.0	(23,286.6)
2054	237634	77231.0	77,103.0	(128.0)	(32.0)	(2.666)	52,430.0	(24,800.9)
2055	242386	78775.6	77,103.0	(1,672.6)	(418.2)	(34.846)	52,430.0	(26,345.6)
2060	267614	86974.6	77,103.0	(9,871.6)	(2,467.9)	(205.659)	52,430.0	(34,544.6)
2070	326220	106021.6	77,103.0	(28,918.6)	(7,229.6)	(602.471)	52,430.0	(53,591.6)
2080	397661	129239.7	77,103.0	(52,136.7)	(13,034.2)	(1,086.182)	52,430.0	(76,809.7)
2085	439050	142691.1	77,103.0	(65,588.1)	(16,397.0)	(1,366.419)	52,430.0	(90,261.1)
2086	447831	145544.9	77,103.0	(68,441.9)	(17,110.5)	(1,425.873)	52,430.0	(93,114.9)
2087	456787	148455.8	77,103.0	(71,352.8)	(17,838.2)	(1,486.517)	52,430.0	(96,025.8)
2090	484746	157542.5	77,103.0	(80,439.5)	(20,109.9)	(1,675.823)	52,430.0	(105,112.5)
2100	590903	192043.4	77,103.0	(114,940.4)	(28,735.1)	(2,394.592)	52,430.0	(139,613.4)

4.3.3 Livelihood Vulnerability Based on Ability to Replant Rice

Most respondents from the three villages could not replant rice after flooding (Figure 19). Several in Thouat were able to replant, indicating that this village was slightly less affected than Taleo and Muangkhai. The majority of respondents said their rice fields were totally destroyed by flooding. Few respondents observed that their crop can recover after flooding, depending on the degree of damage. While rice provides the main income source from agriculture in Champone district, from which 1 ha is estimated to generate 500 US dollars in profit (DAFO, 2015), when farmers are unable to replant after flooding, all stored rice is consumed leaving none for cash sales or consumption in the next season.

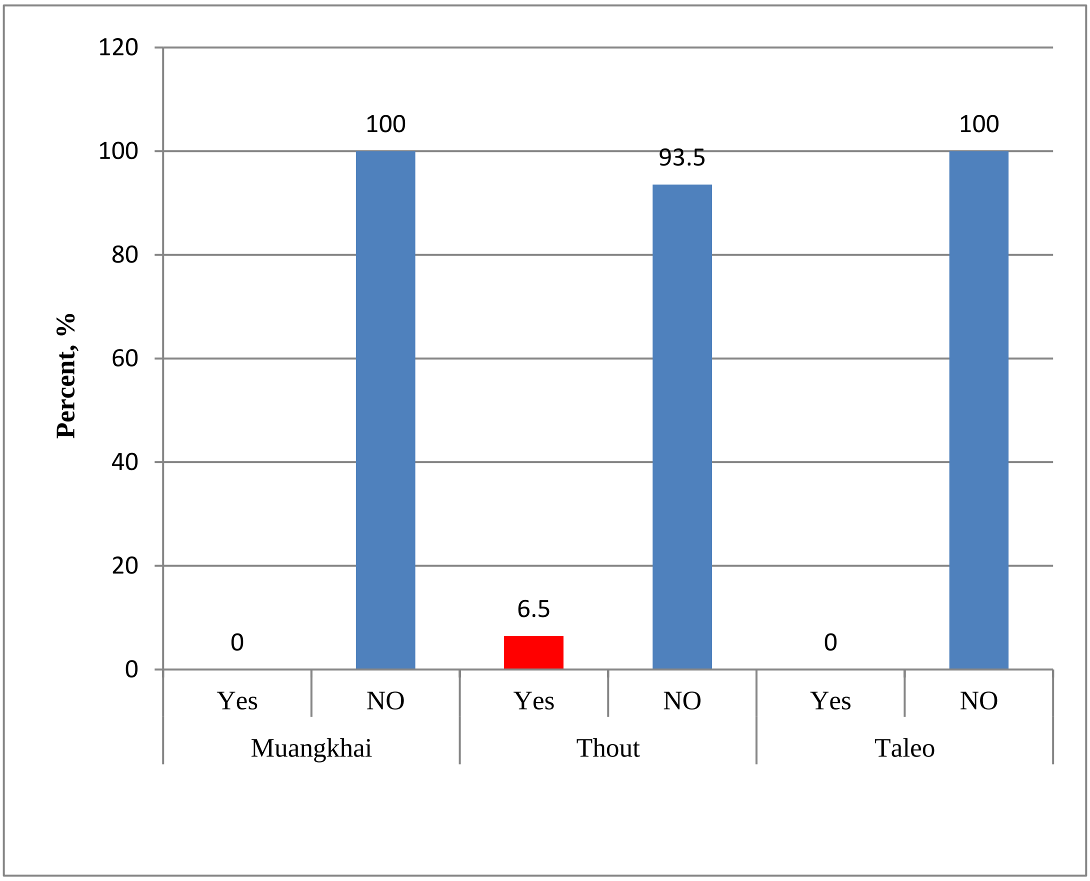


Figure 19. Proportion of respondents able to replant rice after flooding in the study sites.

4.3.4 Storage of Food during Flooding Occurrence

Based on interviews, flooding occurs every year and it is important for farmers to have stored foods. However, because of their economic condition few people could afford to store meat (Figure 20), and most only stored rice. But in reality, farmers' stored rice would ensure they have enough rice for consumption during flooding, but also meant they need to buy more food, including rice, in the meantime.

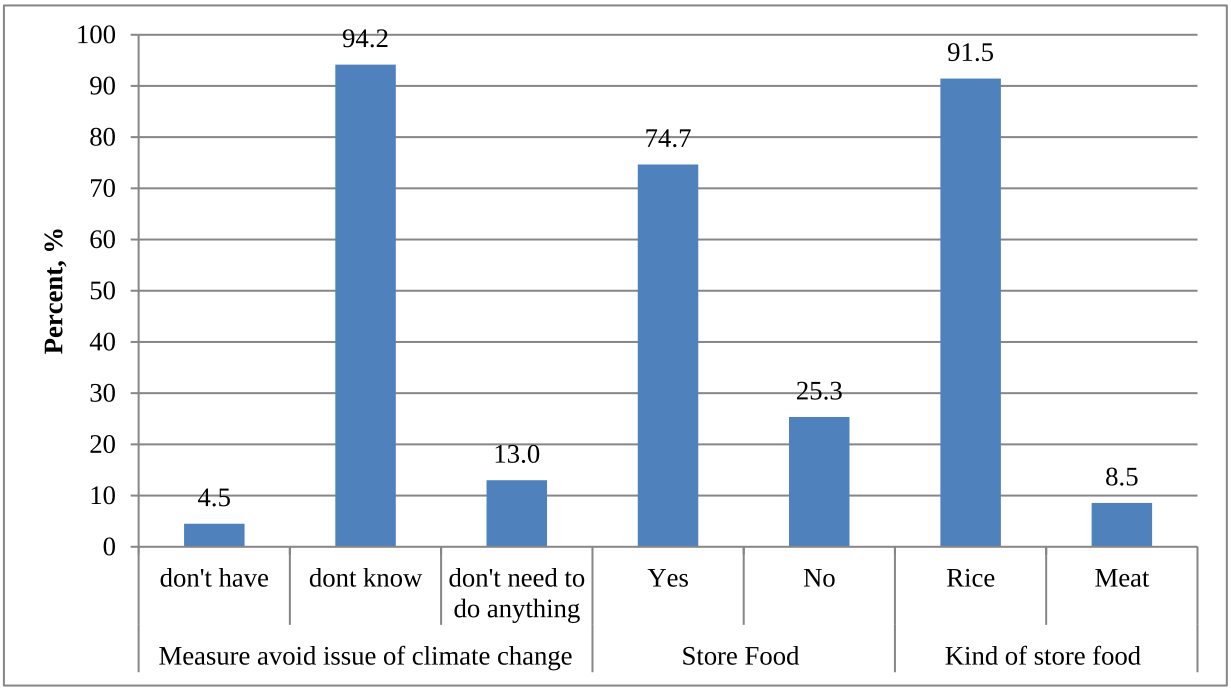


Figure 20. Proportion of respondents who are able to store food in case of flood occurrence.

4.3.5 Hiring Labour to Support Household Rice Production

Just over half of the respondents borrowed money for hired labour (Figure 21), because their family labour was insufficient. Some farmers borrowed cash from other family members who are working outside the village, with an interest rate of 10%, payable after harvest. Others sold their animals to provide cash. While the main source of income the respondents depend on remains the quantity of rice production after harvesting, they could gain enough money to return loans if they are able to avoid flooding from extreme rainfall events, and especially if they can also access sufficient water supply during the dry season.

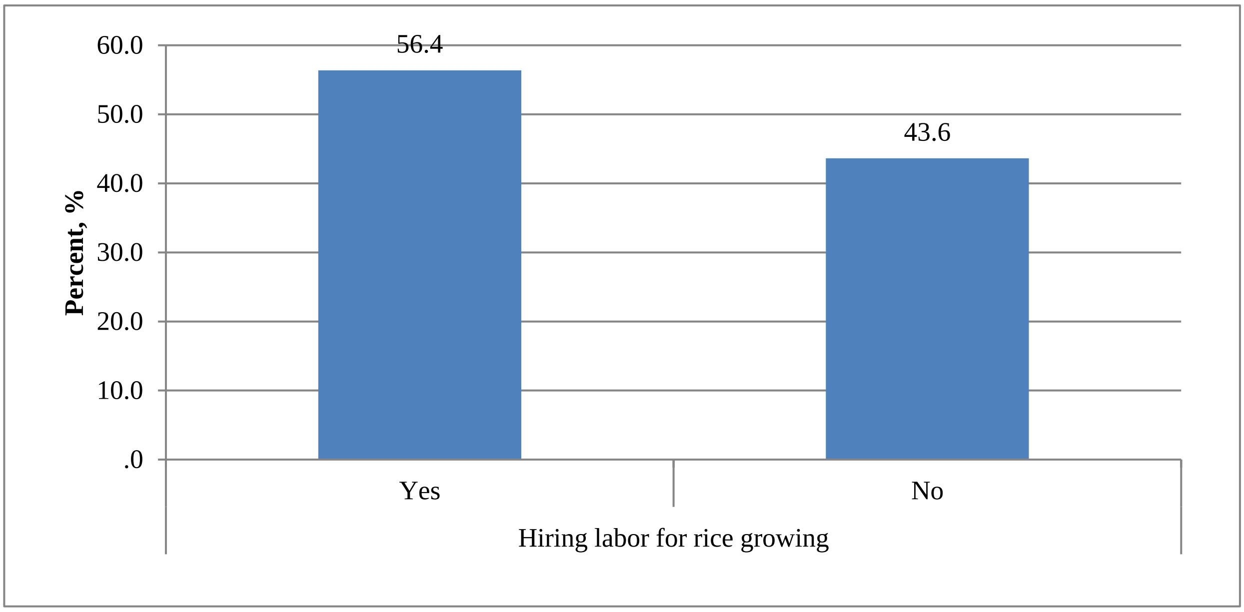


Figure 21. Proportion of respondents who borrowed money for hired labour.

4.3.6 Sources of Cash in Times of Need

The respondents' sources of cash during times of need, for basic needs and school expenses of their children, came from savings, selling of livestock and poultry, informal borrowing from people in the village, and from household members working outside the village (Figure 22). In Taleo and Muangkai, savings were the predominant source of cash while selling livestock was the main source of cash in Thouat.

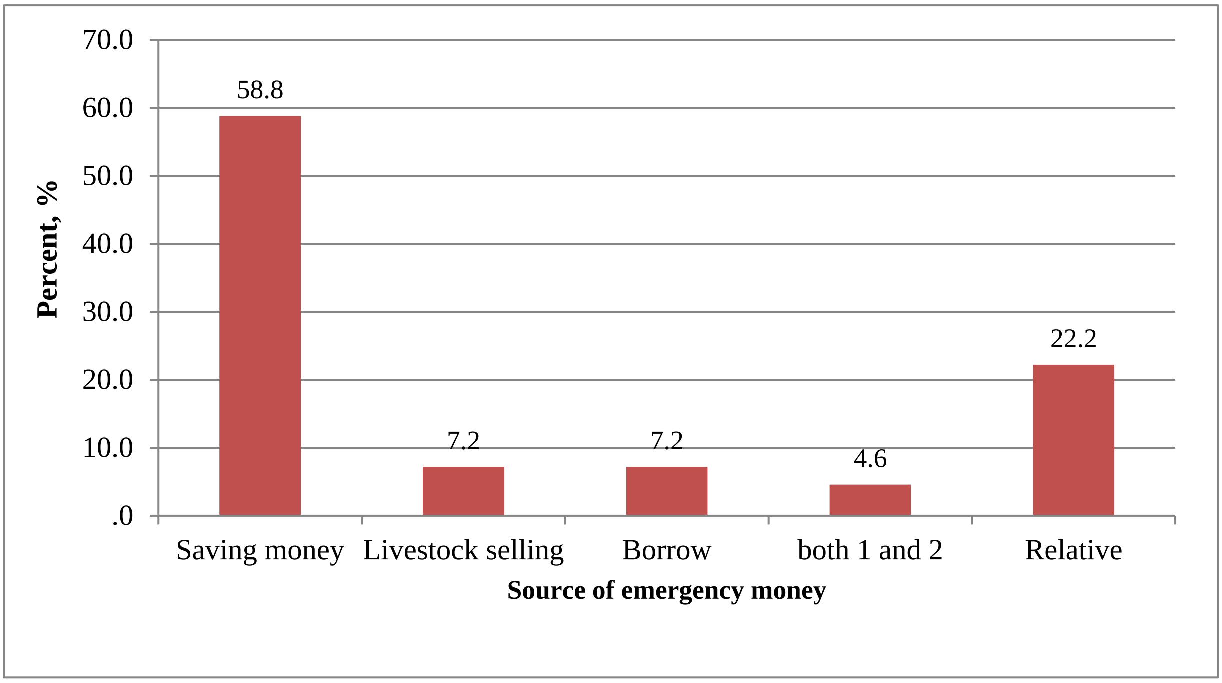


Figure 22. Sources of emergency money of respondents from the three villages.

4.4 Community adaptation options to ensure rice security

4.4.1 Water Accessibility and Management for Rice Production

While rice production in the study communities is almost entirely rainfed, according to interviews including with the village head, a number of respondents in Thouat village, located in the middle section of the Xe Champhone River, could plant two rice crops by accessing irrigation (Figure 23). Most respondents in Muangkai in the north and Taleo in the south part of the district almost completely depended on the overflowing river for irrigation and only planted a rainy season crop. In Thouat village, only 46% of the paddy area (as well as just 0.7% of Taleo village) could be irrigated by pumping water from the river or ponds during the dry season, but the cost was higher than the benefit overall. The head of village reported that in 2017 only 5 ha of rice was grown by using their pond because lack of water, and some respondents could not save the water. Most farmers preferred not to plant during dry season and instead went to the provincial capital of Savannakhet or neighboring Thailand to find jobs.

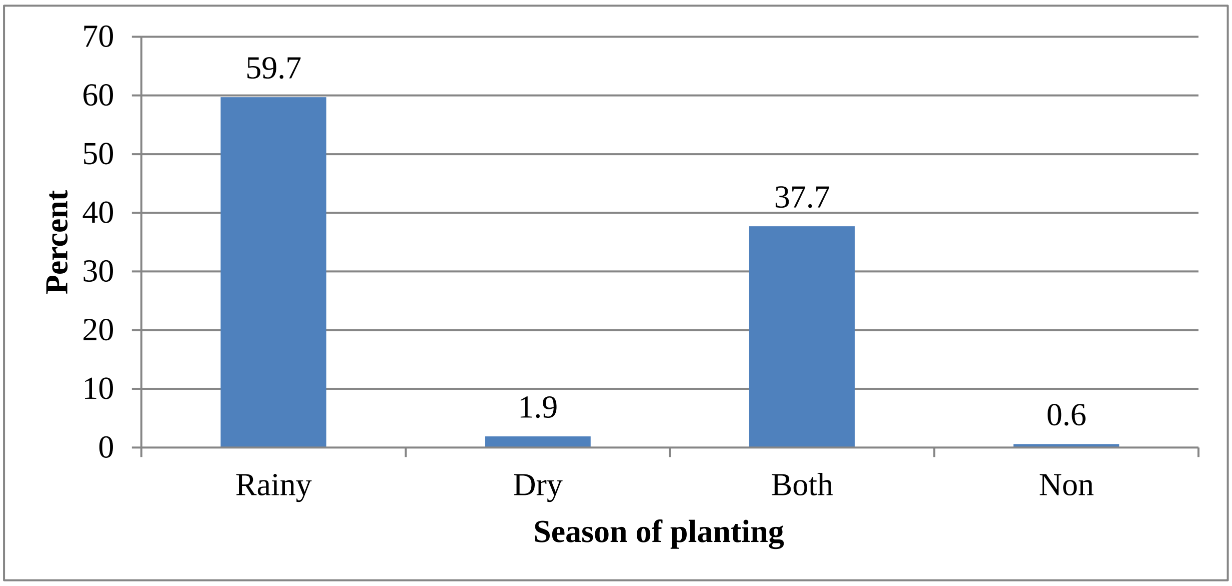


Figure 23. Proportion of respondents able to plant rice in the rainy season versus dry season at the study sites.

4.4.2 Fishing and Pond Use at the Study Sties

Open fishing in the Xe Champhone river is a common supplementary livelihood. In Muangkhai and Thouat village, the respondents built ponds near the river or irrigation canals and constructed canals to the waterway which trap fishes when the river or irrigation canal overflows. They block the waterway to prevent fishes from escaping, although with high floodwater the trapped fishes can escape. According to the respondents in Taleo, most of their ponds were many decades old from the war period, and the villagers could not build more by themselves due to limited income.

Figure 24. Ponds at the study sites.

4.4.3 Irrigation Development

Champhone District has 25 pumping stations for the irrigation system to support agriculture on 18,600 ha, of which 13,200 ha is rice land, although the study sites are not included in this area and are therefore mostly dependent on rainwater for rice cultivation. According to interviews, irrigation expansion had been discussed in Thouat and Taleo villages since 2011, but no follow-up implementation had taken place until the time of the research, and farmers were not aware of any further information about the project, although more than 60% of respondents expressed awareness of irrigation development plans (Figure 25). In Mouangkhai, no such work had been undertaken at the time of the research. According to the Irrigation Division of the Provincial Agriculture and Forestry Office, the project is under review and consideration for budget, and could commence in 2020. If the project becomes operational, this could strengthen the water supply to the farmers sufficiently to produce a dry season rice crop and replace damage and losses from the flooding.

4.4.4 On-Farm Water Management

In addition to awareness of irrigation development plans in the study sites, Figure 25 shows that almost 50% of respondents were unable to answer why they did not find on-farm water storage methods, indicating that no information or methods had been made accessible to the study sites before the period of the survey. About 20% stated that there was simply no water, 15% that they did not know how to find the source, and more than 10% mentioned lacking budget. After our explanation of water harvesting, 115 households or 74.5% of respondents stated awareness of water harvesting, and farmers indicated interest to participate in a program for this purpose.

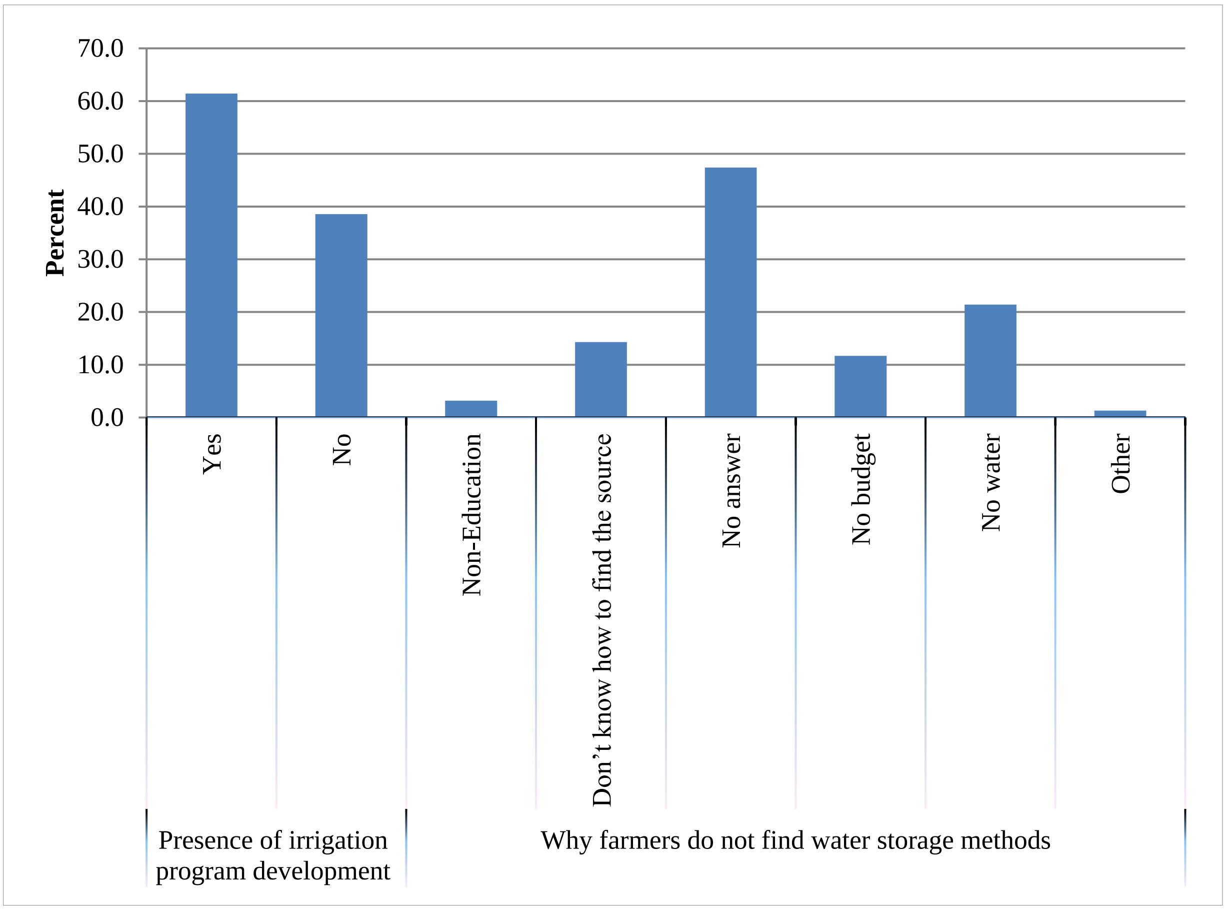


Figure 25. Awareness of irrigation development and water management methods in the study sites.

4.5 Water harvesting method availability for community resilience

Based on the results of surveys in the study sites, table 5 below presents the summary of community capacity of the villages using SWOT analysis (Strengths, Weakness, Opportunities and Threats). This identified the possibility/suitability of water harvesting methods to support water use for agriculture, especially paddy production, based the facilities, demographic profile and the capacity of farmers as indicators of community vulnerability. Of the water harvesting methods appropriate to the study sites, pond irrigation was the most suitable for the areas due to its strengths based on available rainfall. Because most of population are involved in rice growing, there are a large amount of farmers willing to continue in agriculture. On the other hand, poor water management, lack of changing the planting calendar, low education and non-tolerant rice varieties were weakness, and crops were vulnerable to disease and impacts of climate change, especially flood and drought, during the year in different seasons.

Table 5. SWOT analysis identifying community adaptive capacity.

Strengths	Weaknesses	Opportunities	Threats
- Rainfall availability - Large number of farmers. - Rice varieties. - Traditional knowledge of farming. - Education institutions. - Domestic market - Opened for new knowledge. - Willing to pay for some amount of water harvesting techniques. - Complementary income. - Government Assistant. - Irrigation committee. - Some projects active.	- Lack of water management, covering only small area and lack of budget for investment - High age - Lack of tolerant varieties of flood and drought - Crop calendar following rain availability - Low education, lack of institutions for promoting adaptive agriculture - Low output crop production - Lack of materials - Low income - Small scale and limited varieties - Located far from the villages - Lower management skills and time conflicts for meeting - No successful project on water harvesting	- **Pond Harvest water, Irrigation canal** - changing crop calendar and cropping mechanism - Outside trainers from education institutions - Supply to the city - Using cheaper materials and easy to find nearby - Multi-crops/ non-mono crop planting - Training on agriculture - Community based management	- Climate change impacts (flood/drought) - Disease

Rice production has significant correlation with household income and farm size ($P<0.01$) (Table 6), as well as the number of household members, their education and age. This in agreement with other studies such as Bornales (2004) in Mt. Malindang, Philippines, in that those with higher income can afford to purchase farm inputs to enhance rice production, combined with using greater experience in maximizing yields. Adaptation that is specific to social factors such as gender, age, health, social status, ethnicity, and class could reduce vulnerability to impacts of climate change (Smit et al., (2001); Adger et al., (2009)).

Table 6. Correlation between rice production and socio-economic factors.

Various	Number of Household	Age	Gender	Education	Occupation	HH income	Rice size	Rice Variety	Have fish pond	Source of emergency money	Rice Production
Number of Household	1	.092^{ns}	.058^{ns}	.045^{ns}	.183*	.168*	.085^{ns}	.020^{ns}	.105^{ns}	306**	181*
Age		1	.018^{ns}	.214**	.209**	.110^{ns}	.022^{ns}	.029^{ns}	.012^{ns}	-.060^{ns}	.067^{ns}
Gender			1	.238**	-.019^{ns}	.138^{ns}	.141^{ns}	.133^{ns}	-.153^{ns}	.146^{ns}	.232**
Education				1	.242**	.438**	.128^{ns}	.215^{ns}	.176^{8}	-.047^{ns}	.134^{ns}
Occupation					1	.372**	.029^{ns}	.130^{ns}	.082^{ns}	.131^{ns}	.201*
HH income						1	152^{ns}	.099^{ns}	.143^{ns}	.003^{ns}	.274**
Rice size							1	.232^{ns}	.208*	.164^{ns}	.499**
Rice Variety								1	.089^{ns}	-.150^{ns}	-.193^{ns}
Have fish pond									1	-.313**	-.432**
Source of emergency money										1	.330**
Rice Production											1

ns. Not significant*. Significant at the 0.05 level **. Significant at the 0.01 level

4.6 Potential for Water Management to Reduce the Community Vulnerability and Strengthen Livelihoods

Table 7 presents the estimated rice production and consumption in Champhone district in 2016 to 2090 while applying water harvesting to improve rice production. The projection shows that improving water management indicates increasing rice production by 176% in response to the variation in rainfall in Champhone district. Without applying water harvesting, rice production was stable until 2034, so this means in the next 16 years farmers will likely face increasing food insecurity, but improving water resource management could increase production into the future (projected to increase up to 2085). On the other hand, water harvesting such as mini-reservoirs with a dimension of 7m x 2.5m x 3m can be used to collect water in the rainy season to use for irrigation in the dry season, which could increase output by 176% for crops such as maize, peanut, cassava and vegetables (Irawan et al., 1999). This would reduce present vulnerability to climate change due to farmers depending only on rainy season rice production for their livelihoods.

Table 7. Projection of on-farm reservoir reducing vulnerability and increasing rice production.

Year	(1) Population	(2) Rice Consumption (Ton)	WITHOUT FLOODING				WITH FLOODING			
									On-Farm Reservoir with 176% Increasing	
			(3) Rice Production (Ton)	(4) Available Rice for cash (Ton)	(5) Income from Rice (USD)	(6) Income per Month (USD)	(7) Rice Production (Ton)	(8) Rice Deficit (Ton)	(9) Rice Productio n (Ton)	(10) Rice Deficit (Ton)
2016	111970	36390.3	77,103.0	40,712.8	10,178.2	848.182	52,430.0	16,039.8	144,706.9	108,316.7
2017	114209	37118.1	77,103.0	39,984.9	9,996.2	833.020	52,430.0	15,312.0	144,706.9	107,588.9
2018	116494	37860.4	77,103.0	39,242.6	9,810.6	817.554	52,430.0	14,569.6	144,706.9	106,846.5
2019	118823	38617.6	77,103.0	38,485.4	9,621.3	801.779	52,430.0	13,812.4	144,706.9	106,089.3
2020	121200	39390.0	77,103.0	37,713.0	9,428.3	785.688	52,430.0	13,040.1	144,706.9	105,316.9
2025	133815	43489.7	77,103.0	33,613.3	8,403.3	700.277	52,430.0	8,940.3	144,706.9	101,217.2
2030	147742	48016.2	77,103.0	29,086.8	7,271.7	605.976	52,430.0	4,413.9	144,706.9	96,690.7
2034	159921	51974.2	77,103.0	25,128.8	6,282.2	523.516	52,430.0	455.8	144,706.9	92,732.7
2035	163119	53013.7	77,103.0	24,089.3	6,022.3	501.860	52,430.0	(583.7)	144,706.9	91,693.2
2040	180097	58531.4	77,103.0	18,571.6	4,642.9	386.908	52,430.0	(6,101.4)	144,706.9	86,175.5
2045	198841	64623.4	77,103.0	12,479.6	3,119.9	259.991	52,430.0	(12,193.4)	144,706.9	80,083.5
2050	219537	71349.5	77,103.0	5,753.5	1,438.4	119.865	52,430.0	(18,919.5)	144,706.9	73,357.4
2053	232974	75716.7	77,103.0	1,386.3	346.6	28.882	52,430.0	(23,286.6)	144,706.9	68,990.3
2054	237634	77231.0	77,103.0	(128.0)	(32.0)	(2.666)	52,430.0	(24,800.9)	144,706.9	67,475.9
2055	242386	78775.6	77,103.0	(1,672.6)	(418.2)	(34.846)	52,430.0	(26,345.6)	144,706.9	65,931.3
2060	267614	86974.6	77,103.0	(9,871.6)	(2,467.9)	(205.659)	52,430.0	(34,544.6)	144,706.9	57,732.3
2070	326220	106021.6	77,103.0	(28,918.6)	(7,229.6)	(602.471)	52,430.0	(53,591.6)	144,706.9	38,685.3
2080	397661	129239.7	77,103.0	(52,136.7)	(13,034.2)	(1,086.182)	52,430.0	(76,809.7)	144,706.9	15,467.2
2085	439050	142691.1	77,103.0	(65,588.1)	(16,397.0)	(1,366.419)	52,430.0	(90,261.1)	144,706.9	2,015.8
2086	447831	145544.9	77,103.0	(68,441.9)	(17,110.5)	(1,425.873)	52,430.0	(93,114.9)	144,706.9	(838.0)
2087	456787	148455.8	77,103.0	(71,352.8)	(17,838.2)	(1,486.517)	52,430.0	(96,025.8)	144,706.9	(3,748.9)
2090	484746	157542.5	77,103.0	(80,439.5)	(20,109.9)	(1,675.823)	52,430.0	(105,112.5)	144,706.9	(12,835.6)
2100	590903	192043.4	77,103.0	(114,940.4)	(28,735.1)	(2,394.592)	52,430.0	(139,613.4)	144,706.9	(47,336.5)

[1] Population growth rate= 2.1%

[2] Rice consumption= 0.36*Population

[3] Rice production without severe flood= 3 ton/ha* Rice area (base on the land use of district for rice growing)

[4] Excess rice for cash= Rice production – Rice consumption

[5] Income from rice = Excess rice (ton)* 200USD/ton

[6] Income per month/household= Income from rice/ Number of Household

[7] Rice production during severe flood= production without flood – 31% (Production without severe flood)
[8] Rice deficit for rice consumption

[9] Rice production during severe flood with pond= production with+176% (Production increasing)

[10] Rice deficit during severe flood with pond= Rice production during severe flood with pond- Rice consumption

According to interviews, farmers were interested in water harvesting even if they understood that there was not enough water for rice growing, but were also interested in participant learning on the methods for planting other crops such as vegetable, bean, corn etc (Figure 29). According to the group discussion Muangkhai and Taleo were most interested in on-farm reservoirs, while Thouat mostly considered expanding the irrigation canal but was also interested on on-farm reservoirs.

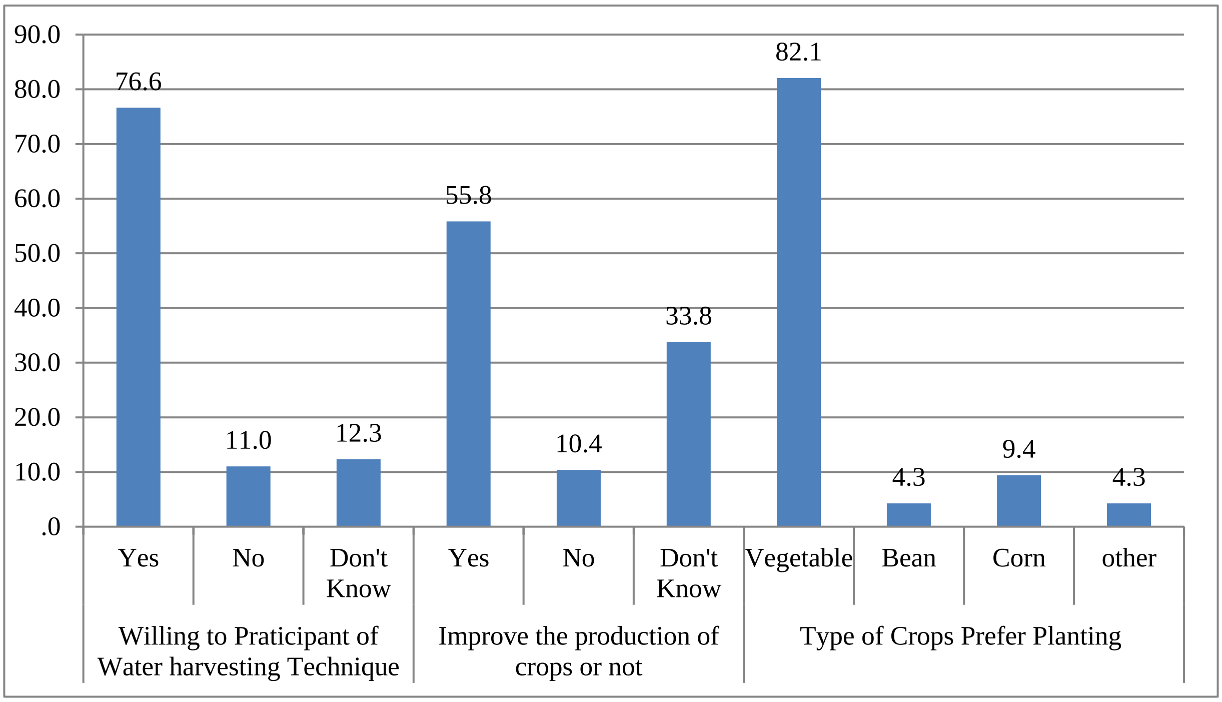


Figure 26. Farmer’s opinions on how to strengthen their livelihoods.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study has assessed the vulnerability and adaptation of rice production systems, farming communities and their livelihoods to flooding and extreme rainfall events in the villages of Muangkhai, Thouat and Taleo in Champhone District, of Savannakhet Province, Lao PDR. These villages are located on the floodplain near the meandering Xe Champhone river, and largely dependent on rainfed rice production for their livelihoods.

A key contribution of the research design has been to combine study of climatic conditions with analysis of social data and institutional capacity at different scales, with the aim of supporting community members to identify ways to protect their water supply against climate variability through storage methods, and also to understand rainfall variability and how to adapt crop types. The study clearly reveals inevitable challenges that the communities will have to respond to in the face of climate change. As developing countries are highly dependent on agriculture, there are ever growing concerns that changes in weather variability will further threaten the welfare and food security of already highly vulnerable rural households and pose a serious challenge to development efforts. In light of this impending threat, it is imperative that we have a deeper understanding of the impact of weather extremes on the poor and the effectiveness of current coping mechanisms. In this study, hydrological, social and economic analyses have shown rice production in the study locations to be highly vulnerable to flooding, in combination with the difference in values of water balance calculations in the Xe Champhone River, to describe water conditions and management for agriculture in the dry season and rainy season in upstream, middle stream and downstream locations. The hydrology analysis estimated intensity of the rainfall in 50, 100, 200 and 400 year periods and runoff of surface water in different seasons by using rainfall data from 1995 to 2015, combined with previous flood assessments to determine the area of physical exposure to climate change, especially extreme rainfall in the study sites. Survey and key informant interviews of households and village officials and heads of various government offices in the province and Vientiane, respectively, were conducted. Exposure to flooding and extreme rainfall events; biophysical, social and economic sensitivity and vulnerability; and overall vulnerability were determined. Severe flooding usually occurred in September and October, resulting in insufficient rice supply. Non-flood tolerant rice varieties remain in use, resulting in low or non-existent rice yields during the worst flooding. Meanwhile, the farms are rainfed and depend on the overflowing river where irrigation is possible, hence the high sensitivity of the rice production system to extreme events. This sensitivity is both driven by and contributes to the socioeconomic vulnerability of the communities, lack of water for rice production in dry season and non-adaptation in terms of how to store water from the rainy season for use in dry season.

The respondents generally farm about 1 ha of rainfed lowland rice per household, which is irrigated where possible by the overflow of the river. Farmers used non-flood tolerant rice varieties and grew rice only for one cropping a year. They depended mainly on household labour. The rice land was normally affected by floods, while in the dry season most of the respondents could not grow rice due to lack of water supply. Without flooding, rice production is adequate for household rice consumption even with one cropping. Only Thouat villagers had enough money for their basic needs from the occasional sale of rice but this was still low. Muangkhai and Taleo villages meet the needs of the family from other forms of income, including wage labour. With severe flooding, villagers would not have enough for food as early as 2034 because they cannot grow rice during the dry season due to lack of available irrigation water.

The majority of the respondents have a monthly income of not more than USD187. They generally have low level of education and are dependent on rice as the main source of income. Their houses are on stilts and generally located at higher elevations to avoid flooding. The farmers raised cattle, buffalo and/or pigs underneath their houses. They have poor access to health services, and roads are not passable during flooding. The low level of income, lack of non-rice livelihoods with better income, low level of education for better employment opportunities, and poor social services and infrastructure make the communities more vulnerable to flooding when there are extreme rainfall events and drought in dry season.

Strengthening the climate change resilience of the communities in sustainable water management requires significant planning considerations at different scales, including the community, district, province and nation by a range of flow and stock adaptation options that should be considered in an integrated way to form local adaptation strategies, as presented in the below recommendations.

5.2 Recommendations

5.2.1 Adaptation Strategies on Water Management for a Climate Change Resilient Community

The final specific objective of this study as set out in the introduction was d) provide research aimed at sustainable water management in Lao PDR for the future, to assist other projects and help communities cope with climate change impacts that may affect their water resources and prevent loss of crops. This study considers integrated flow and stock adaptation strategies (Agrawala et al., 2010) as necessary to increase resilience to climate change impacts in the three study villages. These are also part of different levels of adaptation at community, district, province and national scale, but focus on how people can manage water locally based on adaptive capacity and climatic conditions (Table 6). Basic community-level recommendations are to expand the use of on-farm reservoirs, consider changing crop calendars, and raising livestock as well as planting other crops with lower water consumption as options to diversify livelihoods and increase income sources. More investment at district level is needed to provide training to farmers on different agricultural approaches and technologies, water harvesting, on-farm water management and also off-farm activities to upgrading local skills and knowledge, and provide the communities with better off-farm employment opportunities. Provincial level recommendations are to conduct soil analysis and provide information for farmers so they can plan and implement rice production, as well as watershed and irrigation development to benefit more areas in the dry season. Moreover, the province could develop project planning to improve irrigation for the purpose of applying for central government funding or donor funding from non-government organisations, though this needs to consider community participation to enable successful achievement. National level recommendations include providing budget and policymaking on water management that responds to climate change. Since climate change impacts on water resources will become more significant, national policy needs to promote different scales of water management to respond to potential water crises. Table 8 summarises these recommendations in terms of flow and stock adaptations. Flow adaptation covers shorter term options that are relatively cheap to put in place, and provide immediate benefits. Stock adaption requires higher investment for long-run benefits that might not be immediately felt by the community, and are instead preparing for major impacts of future climate change that have not happened yet (Agrawala et al., 2010). Higher confidence is therefore needed in the ability of stock adaptation options to cope with future climate risks than flow adaptations which adjust to current, immediate risks.

Table 8. Recommendations for adaptation strategies on water management and related factors.

Scale	Flow Adaptation	Stock adaptation	Remark
Community	Planting high-value and low water-consuming crops after rice	Disaster risk reduction team	Planting of legumes, corn, sorghum and other crops after rice to use the residual moisture in the paddy after harvesting rice would add to the food supply during rainy months and provide alternative income to rice.
	Small scale dikes		Green soybean and vegetables can be planted on the sides of dikes to augment protein supply of the households.
	Crop calendar changes		Reduce flood damage.
	Livestock		Additional income during drought
District	Training and promoting on water harvesting and on-farm management	Pond irrigation	Storage of rainwater to reduce flood and drought impacts.
	Market Accessibility	Tolerant rice varieties and crops	Increasing income, resistant to flood/drought and using less water.
		Disaster risk management unit	Support local information.
		River bank engineering	Reduce impacts from water overflow.
		Off-farm activities	Upgrading local skills and knowledge to provide the communities with better off-farm employment opportunities; fruits, vegetables, and medical plant production around households can help augment food supply while excess products can be sold in local markets; livestock should be kept in enclosures to prevent damage to crops; root crops can serve as survival crops during flooding.
Province	Soil Analysis	Irrigation and watershed development	Upgrading irrigation together with watershed improvement of the source of irrigation water is necessary to benefit more areas in the dry season, which would reduce exposure of rice crops to flooding and provide water in dry season; riparian zones of the river have to be improved to prevent stream bank erosion
		Economic Acceptability	Explore social provision and livelihood adaptation options for farmers to contribute to wider economic and community development; encourage economic and efficient use of irrigation water in dry periods by building in opportunity costs of irrigation water supply while also considering farmers' economic capacity to cover irrigation costs
National	Public funding	Policy on water management in response to climate change	Climate change impacts on water resources will become more significant –national policy needs to promote different scales of water management to respond to water crises

5.2.2 Recommendations for Future Research and Development

Based on the results of this study, the recommendations for future research and development are as follows:

1. Promoting water harvesting for crops and vegetables to diversify planting rice in non-irrigated areas to improve income.
2. Research cropping systems after the rice harvest by planting high-value crops in elevated areas and around households to improve food supply.
3. Development of:

   (a) Disaster Risk Reduction Management and Climate Change Adaption (DRRM-CCA) committee in each village.

   (b) Watershed management to improve the source of irrigation water and irrigation system.

Some of these recommendations are already in place under current government policies in other locations of Laos, and can be applied in the study locations, together with the additional recommendations above, to better support local adaptive capacity.

Table 9. Recommendations of the study compared with current government policies.

Study recommendations	Current government policies
1. Promote water harvesting	The current Law on Water and Water Resources refers to reservoirs as a "system of water storage by pond digging, and storing water from streams, and rivers to have enough water for use and storage for livelihoods, agriculture, and social and environmental sustainability" (GoL, 2017, p3, author's translation). The document highlights the importance of rainfall harvesting methods to ensure sufficient water supply in agriculture to support food security, and any activity of utilisation of water for increasing agricultural production that is not harmful to the environment. Based on the results of the present research, on-farm reservoirs are also a recommended method to conserve excess water from the rainy season for use in dry season, and could help to increase agricultural production in remote areas where people are most heavily dependent on farming, reducing community vulnerability.
2. Research high value crops after rice harvest	The high reliance of Lao people on agriculture and especially rice production means that for thousands of farmers, most of their income still depends on a highly water-intensive crop. Planting high value non-rice crops in the dry season has been recommended by government and international organisations, though this has to be based on crops able to tolerate drier conditions which are also good for soil. Part of the long-term strategy of the government is to continue promoting commercial crops and widespread use of improved seed varieties (MAF, 2015). However, according to the Mekong River Commission Climate Change Adaptation Initiative (CCAI), which has conducted projects in Champhone district, people lack knowledge on climate change impacts, adaptation options and planning in general, including options on planting different crop varieties (MRC, 2014b). In addition, this study recommends finding suitable cash crops to improve the livelihoods of farmers and diversify their incomes from depending only on growing rice in rainy the season.
3. (a) DRRM-CCA	One of the major concerns linked with climate change is the potential for increased extreme events in terms of both frequency and intensity. Information on the changing weather should be up to date and locally accessible so farmers will be able to plan and adapt to variable weather conditions that may impact

	their livelihoods. The government assigns local DRRM-CCA units and warning systems to be the focal points of information delivery from the central to local level to prepare for and reduce the impacts from extreme events (MAF, 2014). District authorities have a natural disaster foundation which supports the monthly salary of each government official and member of the monitoring committee from different offices in the district, mainly under the responsibility of the District Office of Natural resources and Environment, Office of Labour and Social Welfare office and district authority. The budget will be used to help people during disasters and also for preparation activities. This issue requires strengthened consideration in future to respond to stronger climate change impacts and with knowledge gaps such as those identified in this study, relating to methods of water harvesting and storage.
3. (b) Watershed management and irrigation improvement	Irrigation development is significant for supporting farmers to increase production by enabling more than one cropping season, to ensure food security and income. At the same time, the irrigation sector needs to consider watershed ecology balance in its activities, such as riverbank implementation, reforestation, sustainable water utilisation etc. These are main areas of responsibility for the Irrigation Division of the Ministry of Agriculture and Forestry, though at the time of the study a number of projects were being considered but awaiting government funding decisions. International non-governmental organisations also provide financing for water resources management, although often this emphasizes integrated watershed management approaches in response to the rapid development of hydropower projects across the country, and not specifically irrigation (though this may be considered as part of integrated schemes, e.g. World Bank, 2017). The government also seeks to 'climate-proof' existing irrigation systems and acknowledges irrigation and water management infrastructure as adaptive measures to climate change and disasters (MAF, 2015). The irrigation division aims to promote public awareness through various campaigns, including on important annual such as tree planting day, wildlife day, environment day, water day etc.

5.2.3 Recommendations for Regional Applications

Based on the results of this study and review of some cases in similar regions, the considered recommendations for applying water management techniques and methods are as follows:

1. Similar methods can be applied in areas where there is available rainfall of more than 1000 mm (IRRI, 1994) to harvest and store for the production of crops such as rice, maize, beans and vegetable, as well as some fish raising.
2. Based on Subagyono and Pawitan (2008), on-farm reservoirs are one option that could be adopted by low-income communities, but can require about 7% of household farm land for digging ponds, and therefore has to consider household adaptive capacities such as income, farm tenure, size of rice area, and other crops, and as long as it is not rice fields, soil type must also be considered.
3. This method is particularly useful for rainfed paddy rice, though other agricultural systems such as large-scale plantation crops such as rubber, oil palm, etc will need to consider different parameters and analytical methods.
4. This method can also be applied in coastal areas for aquaculture, but requires specific materials for instruction (e.g plastic, or cement) to store the water in this case, so cost versus benefits need to be considered.

References

ACTIONAID INTERNATIONAL (2003). Participatory Vulnerability Analysis: A step-by-step guide for field staff. Website: http;//www. Actionaid.org.uk/wps/conten/documents/ PVA520final.pdf

Adger W.N and Barnett J. (2009). Four reasons for concern about adaptation to climate change. Environment and Planning A, 41(12), 2800-2805. http://journals.sagepub.com/doi/abs/10.1068/a42244

African Development Bank (2013). Assessment of Best Practises and Experience in Water Harvesting. Rainwater Harvesting Handbook. https://www.pseau.org/outils/ouvrages/bafd_rainwater_harvesting_handbook.pdf

Aggarwal P. K. and Mall R. K. (2002). Climate Change and Rice Yields in Diverse Agro-Environments of India. I. Evaluation of Impact Assessment Models. https://link.springer.com/content/pdf/10.1023%2FA%3A1013702105870.pdf

Agrawala S., F. Bosello, C. Carraro, K. Bruin, E. Cian, R. Dellink, E. Lanzi (2010). Plan or React? Analysis of Adaptation Costs and Benefits Using Integrated Assessment Models. *OECD Environment Working Papers* No. 23. OECD Publishing. http://dx.doi.org/10.1787/5km975m3d5hb-en

ASIA DEVELOPMENT BANK (2009). International Food Policy Research Institute. Building Climate Resilience in the Agriculture Sector in Asia and the Pacific, 66-78.

Asian Development Bank (2006). Socialist Republic of Viet Nam: Viet Nam Water Sector Review. Technical Assistance Report. Hanoi: ADB.

Asian Development Bank (2009). Water: Vital for Viet Nam’s Future. Hanoi: ADB.

Biltonen E., Hussain I. and Tuan D. D. (Eds). (2003). Pro-poor Intervention Strategies in Irrigated Agriculture in Asia. Vietnam country paper. Colombo: International Water Management Institute.

Bornales R. G. (2004). Adaptation and vulnerability of Subanen community to the adverse environmental conditions in Mt. Malindang National Park, Philippines. Journal of environmental science & management, vol. 7, no. 1, 2004, p. 56.

Boulidam S. (2012). Simulation of Climate Change Impact on Lowland Paddy Rice Production Potential in Savannakhet Province, Laos. https://zidapps.boku.ac.at/abstracts/download.php?dataset_id=10413&property_id=107.

Bradshaw M. J., Abbott A. J. and Gelsthorpe A. P. (1978). The Earth's Changing Surface. Wiley.

CATLING H. D. (1992). Rice in Deep Water. London: International Rice Research Institute and Macmillan Press. 542 pp.

De Silva S., Johnston R., Sellamuttu S. (2014). Agriculture, irrigation and poverty reduction in Cambodia: Policy narratives and ground realities compared. CGIAR Research Program on Aquatic Agricultural Systems. Penang, Malaysia. Working Paper: AAS-2014-13. http://publications.iwmi.org/pdf/H046294.pdf

Department of Agriculture (2015). Annual crop production statistics.

Diaz H. F, Markgraf V. (Eds). (2000). El Niño and the southern oscillation, multiscale variability and global and regional impacts. Cambridge University Press, Cambridge.

Doan D.T., Satoh M. and Nguyen T.N. (1996). Impact of production privatization on on-farm water management in the Red River Delta, North Vietnam. Journal of Japan Society of Hydrology and Water Resources, 9 (4), 358-366.

Falkenmark M., Fox P., Persson G., Rockstrom J. (2001). Water Harvesting for Upgrading of Rainfed Agriculture. Problem Analysis and Research Needs. Stockholm International Water Institute, Sweden.

Food and Agriculture Organisation (2003). Agriculture, food and water. ISBN 92-5-104943-2. http://www.saiplatform.org/uploads/Library/agricfoodwater.pdf

Food and Agriculture Organisation (2011). Irrigation in Southern and Eastern Asia in Figures. AQUASTAT Survey 2011. FAO Water Reports, 37. Rome: Food and Agriculture Organisation of the United Nations.

FRANCISCO H. A. (2008). February 13-15. EEPSEA Climate Change Adaptation Conference in Bali, Synthesis of Proceedings, Climate Change: Impact, Adaptation, and policy Responses in South East Asia, 21 pp.

Fredén F. (2011). Impacts of dams on lowland agriculture in the Mekong River catchment. Bachelor's degree thesis in Physical Geography, Department of Earth and Ecosystem Sciences 2011-05-27 at Lund University. https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=2154090&fileOId=2154106

Fulazzaky M. A. (2014). Challenges of Integrated Water Resources Management in Indonesia. Water 2014, 6, 2000-2020; doi: 10.3390/w6072000.

Government of Laos (GoL, 2017). Law on Water and Water Resources. Lao National Assembly.

Hazarika M. K., Bormudoi A., Phosalath S., Sengtianthr V. and Samarakoon L. (2008). Flood Hazard In Savannakhet Province, Lao PDR, Mapping Using Hec-Ras, Remote Sensing AndGis.https://www.researchgate.net/publication/267296211_Flood_Hazard_In_Savannakhet_Province_Lao_Pdr_Mapping_Using_Hec-Ras_Remote_Sensing_and_Gis

Hendrayanto (2004). Watershed and Water Resources Management in Indonesia. http://www.nourin.tsukuba.ac.jp/~tasae/2004/Indonesia.pdf.

Hijioka Y., Lin E, Pereira J. J., Corlett R. T., Cui X., Insarov G. E., Lasco R. D., Lindgren E. and Surjan A. (2014) Asia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V. R., C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White (Eds.)]. Cambridge University Press, Cambridge, United

Kingdom and New York, NY, USA, pp. 1327-1370.https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap24_FINAL.pdf.

Horie T., Matsui T., Nakagawa H. and Omasa K. (1996). Effect of elevated CO2 and global climate change on rice yield in Japan. In: Omasa K., Kai K., Taoda H., Uchijima Z., Yoshino M. (Eds). Climate change and plants in East Asia. Tokyo.

International Rice Research Institute (2011). Indonesia-IRRI cooperation Impact and Challenges Ahead.

Inthavong T., Fukai S. and Tsubo M. (2011). Spatial variations in water availability, soil fertility and grain yield in rainfed lowland rice: A case study from Savannakhet province, Lao PDR. *Plant Production Science*, 14(2), 184-195.

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri R. K and Reisinger A. (Eds.)]. IPCC, Geneva, Switzerland, 104 pp. https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4syr_full_report.pdf

IPCC (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Frontmatter_FINAL.pdf

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R. K. Pachauri and L. A. Meyer (Eds.)]. IPCC, Geneva, Switzerland, 151 pp. http://www.ipcc.ch/pdf/assessment-report/ar5/syr/ SYR_AR5_FINAL_ full_wcover.pdf

Irawan S., Tacconi L. and Ring I. (1999). Stakeholders' incentives for land-use change and REDD+: The case of Indonesia. http://earthinnovation.org/wpcontent/uploads/2013/01/ Stakeholders-Incentives-for-Land-use-Change-and-REDD-.pdf

IRRI (1997). Second Edition. Rice Alamance. Rice Environment, p17-25.

Joffre O., Kura Y., Pant J., Nam S. (2010). Aquaculture for the Poor in Cambodia – Lessons Learned. The World Fish Center, Phnom Penh, Cambodia.

Kattel R. R. (2015). Rainwater Harvesting and Rural Livelihoods in Nepal. SANDEE Working Paper No. 102–15. http://www.sandeeonline.org/uploads/documents/publication/ 1078_PUB_Working_Paper_102_Rishi.pdf

Trenberth K. E. (2011). Changes in Precipitation with Climate Change. Vol. 47: 123–138, 2011 doi: 10.3354/cr00953

Lao Statistical Bureau (LSB, 2015). The 4th Population and Housing Census. Government of Lao PDR, Vientiane.

Le C. V. and Jensen J. R (2014). Individual lift irrigation: A case study in the Cau Son irrigation and drainage area, Red River Basin, Vietnam. Paddy and Water Environment, 12(1), 223-238.

Ministry of Agriculture and Forestry of Laos (MAF, 2009). Annual report: Crop statistics of the Department of Agriculture.

MAF (2014). Plan of Action for Disaster Risk Reduction and Management in Agriculture (2014-2016).

MAF (2015). Agricultural Development Strategy to 2025 and Vision to the Year 2030.

Dore, M. H. I. (2005). Climate change and changes in global precipitation patterns: What do we now? https://doi.org/10.1016/j.envint.2005.03.004

Mekong River Commission (MRC, 2010). Management Information Booklet Series No. 4, Impacts of Climate Change and National Institute of Disaster Management (NIDM) and National disaster Management Authority (NDMA). Handbook on Disaster Risk

Management Mainstreaming in Development. Author. Islamabad. Date visited: March 15, 2013. Website: http://ndma.gov.pk/publiccations_One_UN_DRM/DRR%20 Mainstreaming/13_stardard_handbook_DRM_Mainstreaming.pdf

MRC (2014a). *Local demonstration projects on climate change adaptation: Final report of the first batch project in Lao PDR*. Demonstration Project Series No. 1. Mekong River Commission Secretariat, Vientiane.

MRC (2014b). *Demonstration Project Climate Change Adaptation Initiatives in the Lao PDR.* Conference paper. 2nd Mekong Climate Change Forum: Adaptation to Climate Change in the Transboundary Context. 6-8 October, 2004. Siem Reap, Cambodia.

NGUYEN N. V. (2005) Global Climate Changes and Rice Food Security. www.fao.org/.../15526-03ecb62366f779d1ed45287e698a44d2e.pdf

Oweis T., Prinz D. and Hachum A. (2001) Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments. ICARDA, Aleppo, Syria. 40 pages. http://www.icarda.org/wli/pdfs/Books/Water_harvest_En.pdf

Palaka, R., Prajwala G., Navyasri K. V. S. N. and Anish S. I. (2016). Development of Intensity Duration Frequency Curves for Narsapur mandal, Telangana State, India. http://esatjournals.net/ijret/2016v05/i06/IJRET20160506022.pdf

Peng S., Huang J., Sheehy J. E., Laza R. C., Visperas R. M., Zhong X., Centeno G. S., Khush G. S. and Cassman K. G. (2004) Rice yields decline with higher night temperature from global warming. Proc. Natl. Acad. Sci. U.S.A. 101 (27), 9971–9975.http://www.pnas.org/content/pnas/101/27/9971.full.pdf

Pokhrel Y., Burbano M., Roush J., Kang H., Sridhar V., Hyndman D. W. (2018). A Review of the Integrated Effects of Changing Climate, Land Use, and Dams on Mekong River Hydrology. https://www.mdpi.com/2073-4441/10/3/266/pdf

Raman A., Verulkar S. B., Mandal N. P., Variar M., Shukla V. D., Dwivedi J. L., Singh B. N., Singh O. N., Swain P., Mall A. K., Robin S., Chandrababu, R., Jain A., Ram T., Hittalmani

S., Haefele S., Piep H. P. and Kumar A. (2012). Drought yield index to select high yielding rice lines under different drought stress severities. Rice 2012, 5, doi:10.1186/1939-8433-5-31.

Roth, C. 2014. Rapporteur's synopsis. Forum D: Climate change and natural resource management. In Robins, L. (ed). *A policy dialogue on rice futures: rice-based farming systems research in the Mekong region*. ACIAR Proceedings No. 142. Australian Centre for International Agricultural Research, Canberra.

SEBALD C. (2010). Towards an Integrated Flood Vulnerability Index: Flood Vulnerability Assessment. Ms Thesis. International Institute for Geo-information Science and Earth Observation. University of Twente.

Smit B., Pilifosova O., Burton I., Challenger B., Huq S., Klein R. J. T. and Yohe G. (2001). Adaptation to climate change in the context of sustainable development and equity. In: Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change [McCarthy J. J., O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White (Eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 877-912. https://www.ipcc.ch/ipccreports/tar/wg2/pdf/wg2TARchap18.pdf

Subagyono K. and Pawitian H. (2008). Water harvesting techniques for sustainable water resources management in catchments area. http://www.ied.tsukuba.ac.jp/wordpress/wp-content/uploads/pdf_papers/tercbull08s2/t8supple2_24.pdf.

Suksri P., Moriizumi Y. and Hondo H., Wake Y. (2008). Sustainable agriculture in Thailand: An Evaluation on the Ethanol Production. Digital Asia Discussion Paper Series. DP 08-004. http://www.hondo.ynu.ac.jp/hiroki/sustainable_agriculture_E.pdf

Sweta, L.O. (2014) Early Warning Systems and Disaster Management using Mobile Crowdsourcing, International Journal of Science and Research (IJSR). Volume 3 Issue 4, April 2014. ID: 020131429

Tao F., Hayashi Y., Zang Z. and Sakamoto T. (2007). Global warming, rice production, and water use in China: Developing a probabilistic assessment. https://www.sciencedirect.com/science/article/pii/S2095311914608169#

UNFCCC (2007). Climate Change: Impacts, Vulnerabilities and adaptation in Developing Countries, pp 68.

United Nations Education, Scientific and Cultural Organisation-Institute for Water Education (UNESCO-IHE, 2007). Website: http;//www.Unescoihefvi.free.fr/vunerability.php

Ursula K., Bruguglio L., Mcleod H., Schmall S., Pratt C. and Pal R. (1999). Environmental Vulnerability Index (EVI) to Summarize National Environmental Vulnerability Profiles. SOPAC Technical Report 275.

Vote C., Eberbach P., Zeleke K., Inthavong T., Lampayan R. and Vongthilath S. 2014. The use of groundwater as an alternative water source for agricultural production in southern Lao PDR and the implications for policymakers. In Robins L. (Ed). *A policy dialogue on rice futures: rice-based farming systems research in the Mekong region*. Australian Centre for International Agricultural Research, Canberra.

World Bank (2017). Mekong Integrated Water Resources Management Project Phase 1. Water Global Practice East Asia and Pacific Region.

World Overview of Conservation Approaches and Technologies (2017). On-farm ponds to alleviate the potential impact of seasonal droughts and for increasing crop cultivation and aquaculture (Cambodia). WOCAT https://qcat.wocat.net/en/wocat/technologies/view/technologies_2844/

Yasuyuki K. and Pradip K. S. (1995). Land and Water Resources Management for Crop Diversification in the Chao Phraya Delta, Thailand: A Case Study of Citrus Cultivation in the North Rangsit Irrigation Project. Southeast Asian Studies, Vol. 33, No.2. https://kyoto-seas.org/pdf/33/2/330202.pdf

Appendix 1: Household Interview

(Translate into Lao)

This questionnaire form will be conducted by the researcher and team from the University of Savannakhet, and all information and data will be protected and collected from the team by the researcher.

The purpose of this questionnaire form relates to the researcher's data requirements for PhD research on water use management in the target villages only. The data will not be used for any harmful purpose towards the people or villages of the study sites. The answers for the following questions will be used only for the purposes of the study. There are no right or wrong answers to these questions, but your own honest opinions will be most helpful to us. We will keep your identity unknown and your answers will be treated as strictly confidential. All data will be analyzed by the researcher and will not be shared with others, for the purpose of protecting privacy.

After the researcher has successfully completed the study program, all raw data will be deleted apart from the baseline data used in the study.

Researcher: Outhevy VONGMANY

PhD student. University of Tsukuba, Japan

Email: outhevy@gmail.com

Interviewer's Name: ………………………………………..

Interviewee's Name…………………………………………

Interview Date: ……………………………………..…

Time: from……….. to …………..

Occupation of respondent: …………………………………

Name of the village: ………………………………………..

……………………………………………………………

# of Household Member	**Age**	**Sex (M/F)**	Civil Status	**Education**	**Occupation**	**Place of work**	**Income per month**

No	Question	Coding Categories		Other Comments
1	How many seasons could your planting?	Rainy	1	
		Dry	2	
		Both	3	
		Non	4	
2	Do you produce rice for eat or sale?	Eat	1	
		Sale	2	
		Both	3	
3	If Both, How many percent each?			
4	Is your crop affect by climate change?	Yes	1	
		No		
5	If yes, what is it?			
	Rainy season			
6	Did the rice crop where able to survive?	Yes	1	
		No	2	
7	If No, how much loss?			
	What is your total area of your farm?			
8	What is your variety plant?	Thadorkkham	1	
		Thasano	2	
		Other	3	
9	Size of farm (hectares)	0-1.5	1	
		1.6-2.5	2	
		2.6-3.5	3	
		3.6-4.5	4	
		4.6-5.5	5	
		>5.5	6	
10	Status of land tenure	Owned	1	
		Rented	2	
		Tenant	3	
		Other	4	
11	Number of year in farm	1-4	1	
		5-10	2	
		11-15	3	
		>15	4	
12				
	How much could you harvest your rice yield during that time? (T/Ha)	2.5-3.5	1	
		3.6-4.5	2	
		4.6-4.5	3	
		other	4	
13	Do you have work animals? What are they?	Yes	1	
		No	2	
14	If yes, what happen with them during the flood?			

No	Question	Coding Categories		Other Comments
15	How do you manage them during flooding?	Move to the safe area	1	
		Leave in the same	2	
		other	3	
16	Do you have other farm?	Yes	1	
		No	2	
17	If yes, What are they?			
18	And what happen to them during flooding?			
19	Are you able to plant the rice after the flood gone if your crop totally destroys?	Yes	1	
		No	2	
20	When do you able to plant after flooding? (week/month)			
21	Do you need to hire the labour?	Yes	1	
		No	2	
22	If yes, How do you pay for that?			
23	and where did you get money from during flooding?	Owned money that safe	1	
		Borrow from people	2	
		Member of family	3	
		Other…………	4	
24	Do you have enough rice seed for the next crop after the standing crop has no harvest?	Yes	1	
		No	2	
25	Can you produce enough rice during season to meet one year supply of the family?	Yes	1	
		No	2	
26	If No, how much do you have to buy?			
27	How much per kg?			
28	Did you change your planting period to avoid flood damage?	Yes	1	
		No	2	
29	Do you have a farm in the upland where you could stay and plant crops while the paddy field is flooded	Yes	1	
		No	2	
30	Do you have some livestock?	Yes	1	
		No	2	
31	If yes, What are they?	Poultry	1	
		Pig	2	
		Goat	3	
		other	4	
32	How large are they?	Poultry	1	
		Pig	2	
		Goat	3	
		other	4	
33	Where are they?			

No	Question	Coding Categories		Other Comments
34	Is there safe area where to bring livestock before flooding?	Yes	1	
		No	2	
35	Do you have the fish pond?	Yes	1	
		No	2	
36	Where is it?			
37	How far is it from the field?			
38	How large is your fish pen area?			
39	How much do you pay for building it?			
40	Did the household experience fisheries damage during the floods	Yes	1	
		No	2	
41	Is there the water storage for the whole year?	Yes	1	
		No	2	
	Effect of the flood on the house hold food security			
42	Do you have stored food for consumption when come?	Yes	1	
		No	2	
43	What is it?	Rice	1	
		Beans	2	
		Dried or process fish	3	
		Meat	4	
		Other	5	
44	When/ where do you buy it gone?			
	Effect on domestic water supply			
45	What is your common source of drinking water?	Borehole	1	
		Protected well	2	
		Unprotected well	3	
		Tap water	4	
		Other (Specify)___	5	
46	Was the main source of water affected by the floods?	Yes	1	
		No	2	
47	Do the household receive domestic water supply (explanation) during the onset of flood?	Yes	1	
		No	2	
	Effect on Household Properties			
48	Was your house affected by flood?	Yes	1	
		No	2	
49	If YES, was it	Totally damaged	1	
		Partially damaged	2	
		Unaffected	3	

No	Question	Coding Categories		Other Comments
50	Type of housing material?	Wood	1	
		Semi-Concrete	2	
		Concrete	3	
		Other:	4	
51	Was your house flooded (Put the level in comment box)	Yes	1	
		No	2	
52	If No, how high from the ground?			
53	Was the source of drinking water flooded?	Yes	1	
		No	2	
54	During the flood, did you and your family evacuate your home?	Yes	1	
		No	2	
55	Do you have your own boat?	Yes	1	
		No		
56	Where did you and your family take?	Relative's house	1	
		Neighbor’s/ friend's house	2	
		Elementary school building	3	
		Evacuation centre	4	
		Other government buildings	5	
		Other (specify)	6	
57	How many days did you and your family stay in the shelter before you could go back to your home?			
58	In total, how much will it cost to repaired\replace these damages to your house today?			
59	In total, how much will it cost to replace today?			
60	Have you ever considered moving your family to another place permanent?	Yes	1	
		No	2	
61	If yes, where you consider or plant to move your residence?	Proximity to source of Livelihood	1	
		Proximity to relative	2	
		Very costly	3	
		Other (Specify)	4	
62	If no, why not?			
	Effect on household health Condition			
63	Are there any health facilities in your area?	Yes	1	
		No	2	
64	Was there any disruption in access to health services due to the floods?	Yes	1	
		No	2	

No	Question	Coding Categories		Other Comments
65	Did any of the household members get sick during the floods?	Yes	1	
		No	2	
66	If Yes, Which kinds of diseases were experienced by the household member? Who got sick?			
	Household Member			
67	Has any member of your household lost her/him life because of flood?	Yes	1	
		No	2	
78	What was the cause of death?			
69	What measures have you take to avoid experiencing the same health problems brought by the flood?			
	Effected on Education			
70	Are there any education facilities in your area?	Yes	1	
		No	2	
71	Did any of the school going children in your household experience any disruption in an attendance due to the floods?	Yes	1	
		No	2	
72	If yes, why? (Indicate main reason):			
	Effect on family Cash Requirement			
73	Where do you get cash during emergency while there is flood?			
74	What was the purpose of borrowing money?			
75	How did you repay the borrowed money?			
	Flood impacts on non-rice livelihoods			
76	What are your other sources of family income?	Son/daughter/husband abroad or in the city	1	
		Fishing	2	
		Selling private commodity	3	
		Other employment	4	
77	Is any member of your family employed in any non-farm work (Salary/wage worker)?	Yes	1	
		No	2	
78	How much per month do they get?			
79	How much do they send/ support family?			
80	How your other sources of income were affected?			
81	Due to the flood, did they lose income because they could not go to work?	Yes	1	
		No	2	
82	How did you bring back your livelihood after affected by floods?			

No	Question	Coding Categories		Other Comments
	Dry Season			
	Accessed the water			
83	How much could you harvest your rice yield? (T/Ha)	2.5-3.5	1	
		3.6-4.5	2	
		4.6-4.5	3	
		other	4	
84	Where do you get water supply for rice planting?	River	1	
		Irrigation	2	
		pond	3	
		other source	4	
85	Do you have to pay for water?	Yes	1	
		No	2	
86	If yes, how do you pay and how much?			
89	Can you produce enough during dry season crop for the flooded month?	Yes	1	
		No	2	
87	How many percent do you consume and sell?			
88	Do you need to hire the labour?	Yes	1	
		No	2	
89	If yes, How do you pay for that?	Cash	1	
		Rice	2	
		other	3	
90	What rice variety did you plant?	Thadokkham	1	
		Thasano	2	
		other	3	
91	Is there any issues to disturb your agriculture?	Yes	1	
		No	2	
92	If Yes, What is it?			
	Non Accessed the Water			
93	Is there watershed development program to have more irrigation during dry season?	Yes	1	
		No	2	
94	What is it?			
95	Why don’t you create the pond to storage water?			
96	If there is water available even not enough for rice planting do you want to plant other crop	Yes	1	
		No	2	
97	Yes, what is it?			
98	No, support your answer			
99	Have you ever heard about any water storage method?	Yes	1	
		No	2	
100	Do you think it will help to improve to produce crops?	Yes	1	
		No	2	
		don't know	3	

No	Question	Coding Categories		Other Comments
101	If there are any project about that will you willing to participant the project?	Yes	1	
		No	2	
		don't know	3	
102	Support your answer			
106	Do you think how much you will able to pay for water to your crops?			
107	Support your answer			

Appendix 2: Key Informant Interview

(Translate into Lao)

This questionnaire form will be conducted by the researcher and team from the University of Savannakhet, and all information and data will be protected and collected from the team by the researcher.

The purpose of this questionnaire form relates to the researcher's data requirements for PhD research on water use management in the target villages only. The data will not be used for any harmful purpose towards the people or villages of the study sites. The answers for the following questions will be used only for the purposes of the study. There are no right or wrong answers to these questions, but your own honest opinions will be most helpful to us. We will keep your identity unknown and your answers will be treated as strictly confidential. All data will be analyzed by the researcher and will not be shared with others, for the purpose of protecting privacy.

After the researcher has successfully completed the study program, all raw data will be deleted apart from the baseline data used in the study.

Researcher: Outhevy VONGMANY

PhD student. Tsukuba University, Japan

Email: outhevy@gmail.com

Interviewer's Name: ………………………………………..

Interviewee's Name…………………………………………

Interview Date: ……………………………………..…

Time: from……….. to …………..

Occupation of respondent: …………………………………

Name of the village: ………………………………………..

1. Which public service system does the community have?

No	Items	Affected	How long	What damage	Repaired or no	How much	Remark
1	Warning system						
2	Evacuation center						
3	Transport system						
4	Health service						
5	Schooling of children						
6	Other						
7							
8							

No	**Question**	**Coding Categories**		**Other Comments**
1	Does the community have action plan to adapt to flooding/drought?	Flood	1	
		Drought	2	
2	If yes, What is it?			
3	If No, What is it?			
4	How NGO assist the community preparation for flooding events to avoid loss of lives?			
5	How far from their house is the evacuation center?			
6	Do you have DRR+ CCA in the community?	Yes	1	
		No	2	
7	Do you have DRR+ CCA in the Villages?	Yes	1	
		No	2	
8	What the village DRR+CCA have done?			
9	Is there watershed development program to have more irrigation during dry season?	Yes	1	
		No	2	
		don't know	3	
10	Can it cover the whole area of farmer?	Yes	1	
		No	2	
11	If No, how many was it covered?			
12	What rice variety did you plant to harvest something when the field was affected by flood?			
13	What is the plan of the government to help you to lessen flood damage?			
14	How do livelihood, community organisations and rice agricultural coping strategies to adapt to flooding?			
No	**Question**	**Coding Categories**		**Other Comments**

16	What preparations did the village government make?	Relocation to other areas	1	
		Having emergency drills	2	
		Reinforced/improved houses	3	
		Emergency medical kit	4	
		Attend disaster preparedness workshop	5	
		Other	6	
17	Is there an identified evacuation center?	Yes	1	
		No	2	
18	If yes, does it have enough water, toilets and health services?	Yes	1	
		No	2	

Coping Strategies

a. What is the normal issue of climate change (flooding/drought) in your community? Explain

____

____

b. Are there any village reservoir or big fish pen?

c. If , there is please give the detail (how large, number of year, deep and for what purpose)

…………………………………………………………………………………………

…………………………………………………………………………………………

……………

d. What are the three main coping strategies if any, that people in the community employ during floods/drought?____

e. How frequency are they happen?...

f. When it happen and how long? (month and period)

....

....

..

g. Did they have in the previous?

[ ] 5 years ago [ ] 10 years ago [ ] 15 years ago [ ] other

h. When did you get the information before happen?

[ ] 3 days [ ] 1 week [ ] 1 month [ ] other...........

i. Is the warning help you to prepare to face it? [ ] Yes [ ] No

j. What did you do after you got the inform or know about that?

....

....

..

k. What did you do to management during the flood/drought?
....
....
.. What do you do after flood/drought?
....
....
.. In your opinion, why the flood /drought happen?
....
....

l. What should we do to adaptation/ what does your village need to improving livelihood?.......... ...
....
....

Appendix 3: Characteristics of Xe Champhone River

1. Name of River : Xe champhone
2. Length of River : 169.7 km
3. Catchment Area: 3140 km^2. Catchment area at gauge high: 2733 km^2
4. There are 2 water level station in Xe champhone: Dong hence station, Kengkok Station
5. **Statistics of Flood in Xe champhone River from 1988-2015**

(Zero of Gauge from Mean sea level: 130.378m (MSL))

No.	Year	Maximum Gauge Height	Date observed	Maximum Gauge height reading from MSL	Remark
1	1988	8.12	5-Aug	138.498	Flood + Drought
2	1989	6.75	25-JuL	137.128	
3	1990	7.85	1-Sep	138.228	Flood
4	1991	8.57	20-Aug	138.948	Flood
5	1992	7.26	6-Sep	137.638	
6	1993	6.54	10-Aug	136.918	
7	1994	7.56	31-Aug	137.938	
8	1995	7.81	1-Sep	138.188	Flood
9	1996	10.15	18-28-Sep	140.528	Severe flood
10	1997	8.27	18-Aug	138.648	Flood
11	1998	7.47	17-Sep	137.848	
12	1999	7.80	27- July	138.158	
13	2000	8.37	12-16 Sep	138.448	Flood
14	2001	8.13	12- 13 Aug	138.508	Flood
15	2002	7.70	1-Aug	138.078	
16	2003	7.83	14-Sep	138.208	
17	2004	8.04	11- 12 Sep	138.418	Flood
18	2005	8.52	11-15 Sep	138.898	Flood (2 time)
19	2006	7.72	17-Aug	138.098	
20	2007	8.20	6-11 Oct	138.578	Flood
21	2008	7.72	22-Sep	138.098	
22	2009	7.86	12-14-Aug	138.238	
23	2010	7.93	29- 31-Aug	138.308	Flood
24	2011	8.76	08- 14 Aug	139.138	
25	2012	8.04	04-07 July	138.418	Flood
26	2013	8.00	23 Sept	138.378	
27	2014	8.24	6 August	138.618	
28	2015	8.07	4 Sept	138.448	Flood

Remark: *Historical Maximum of water flood in Xechamphone occurred in 1978 was over 11.26m or 141.638 m (MSL) occurred on 17/8/1978, 28 days flood in that area*

Appendix 3: Possibility Distribution by Using Gumbel's extreme Value Distribution Method

Year	Rainfall in mm for T hours duration							
	p24	p0.08	p0.167	p0.5	p1	p2	p4	p6
Hour	24	0.083	0.167	0.500	1	2	4	6
1995	97	14.67	18.52	26.69	33.63	42.37	53.38	61.11
1996	101	15.27	19.28	27.79	35.01	44.12	55.58	63.63
1997	101	15.27	19.28	27.79	35.01	44.12	55.58	63.63
1998	73	11.04	13.94	20.09	25.31	31.89	40.17	45.99
1999	103	15.58	19.66	28.34	35.71	44.99	56.68	64.89
2000	102	15.42	19.47	28.07	35.36	44.55	56.13	64.26
2001	97	14.67	18.52	26.69	33.63	42.37	53.38	61.11
2002	88	13.31	16.80	24.21	30.51	38.44	48.43	55.44
2003	80	12.10	15.27	22.01	27.73	34.94	44.03	50.40
2004	87	13.16	16.61	23.94	30.16	38.00	47.88	54.81
2005	91	13.76	17.37	25.04	31.55	39.75	50.08	57.33
2006	79	11.95	15.08	21.74	27.39	34.51	43.48	49.77
2007	63	9.53	12.03	17.34	21.84	27.52	34.67	39.69
2008	81	12.25	15.46	22.29	28.08	35.38	44.58	51.03
2009	59	8.92	11.26	16.23	20.45	25.77	32.47	37.17
2010	60	9.07	11.45	16.51	20.80	26.21	33.02	37.80
2011	70	10.59	13.36	19.26	24.27	30.58	38.52	44.10
2012	62	9.38	11.84	17.06	21.49	27.08	34.12	39.06
2013	75	11.34	14.32	20.64	26.00	32.76	41.27	47.25
2014	66	9.98	12.60	18.16	22.88	28.83	36.32	41.58
2015	65	9.83	12.41	17.89	22.53	28.39	35.77	40.95
Mean	80.95	12.24	15.45	22.27	28.06	35.36	44.55	51.00
SD	15.39	2.33	2.94	4.24	5.34	6.72	8.47	9.70

K (frequency factor)	5	10	25	50	100	200	400
Square root 6	2.45	2.45	2.45	2.45	2.45	2.45	2.45
	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Ln(T/T-1)	0.223143551	0.105360516	0.040821995	0.020202707	0.010050336	0.005012542	0.002503
Ln (Ln(T/T-1))	-1.499939987	-2.25036733	-3.198534261	-3.901938658	-4.600149227	-5.295812143	-5.99021
0.5772+Ln (Ln(T/T-1))	-0.922739987	-1.67316733	-2.621334261	-3.324738658	-4.022949227	-4.718612143	-5.41301
K	(0.72)	(1.31)	(2.04)	(2.59)	(3.14)	(3.68)	(4.22)
K	0.72	1.31	2.04	2.59	3.14	3.68	4.22

Rainfall (Pt) corresponding of a given period (T) using Gumbel's distribution										
Duration	Duration	mean	SD	5 year	10 year	25 year	50 year	100 year	200 year	400 year
5 Min	0.083	12.24	2.33	13.92	15.28	17.00	18.28	19.55	20.81	22.07
10 Min	0.167	15.45	2.94	17.57	19.29	21.46	23.08	24.68	26.27	27.86
30 Mim	0.5	22.27	4.24	25.32	27.80	30.94	33.26	35.57	37.87	40.16
1 hr	1	28.06	5.34	31.91	35.03	38.98	41.91	44.81	47.71	50.60
2	2	35.36	6.72	40.20	44.13	49.11	52.80	56.46	60.11	63.75
4	4	44.55	8.47	50.65	55.61	61.87	66.52	71.13	75.73	80.32
6	6	9.70	9.70	16.68	22.35	29.53	34.85	40.13	45.39	50.64
24	24	80.95	15.39	92.03	101.04	112.43	120.88	129.26	137.61	145.95

Intensity of Rainfall (I_t)

Duration (Min)	5 year	10 year	25 year	50 year	100 year	200 year	400 year
5	167.68	184.10	204.84	220.23	235.51	250.73	265.92
10	105.21	115.51	128.53	138.18	147.77	157.32	166.85
30	50.65	55.61	61.87	66.52	71.13	75.73	80.32
60	31.91	35.03	38.98	41.91	44.81	47.71	50.60
120	20.10	22.07	24.55	26.40	28.23	30.05	31.88
240	12.66	13.90	15.47	16.63	17.78	18.93	20.08
360	2.78	3.73	4.92	5.81	6.69	7.57	8.44
1440	3.83	4.21	4.68	5.04	5.39	5.73	6.08

Appendix 4: Projection of Rice production in Champhone District, Lao PDR

Year	Population	Rice Consumption (Ton)	WITHOUT FLOODING				WITH FLOODING			
									On-Farm Reservoir 176%	
			Production (Ton)	Available Rice for cash (Ton)	Income from Rice (USD)	Income per Month (USD)	Rice Production	Rice Deficit (Ton)	Rice Production (Ton)	Rice Deficit (Ton)
2016	111970	36390.3	77,103.0	40,712.8	10,178.2	848.182	52,430.0	16,039.8	144,706.9	108,316.7
2017	114209	37118.1	77,103.0	39,984.9	9,996.2	833.020	52,430.0	15,312.0	144,706.9	107,588.9
2018	116494	37860.4	77,103.0	39,242.6	9,810.6	817.554	52,430.0	14,569.6	144,706.9	106,846.5
2019	118823	38617.6	77,103.0	38,485.4	9,621.3	801.779	52,430.0	13,812.4	144,706.9	106,089.3
2020	121200	39390.0	77,103.0	37,713.0	9,428.3	785.688	52,430.0	13,040.1	144,706.9	105,316.9
2021	123624	40177.8	77,103.0	36,925.2	9,231.3	769.275	52,430.0	12,252.3	144,706.9	104,529.1
2022	126096	40981.3	77,103.0	36,121.7	9,030.4	752.535	52,430.0	11,448.7	144,706.9	103,725.6
2023	128618	41801.0	77,103.0	35,302.0	8,825.5	735.459	52,430.0	10,629.1	144,706.9	102,906.0
2024	131191	42637.0	77,103.0	34,466.0	8,616.5	718.042	52,430.0	9,793.1	144,706.9	102,069.9
2025	133815	43489.7	77,103.0	33,613.3	8,403.3	700.277	52,430.0	8,940.3	144,706.9	101,217.2
2026	136491	44359.5	77,103.0	32,743.5	8,185.9	682.156	52,430.0	8,070.5	144,706.9	100,347.4
2027	139221	45246.7	77,103.0	31,856.3	7,964.1	663.673	52,430.0	7,183.3	144,706.9	99,460.2
2028	142005	46151.6	77,103.0	30,951.4	7,737.8	644.820	52,430.0	6,278.4	144,706.9	98,555.3
2029	144845	47074.7	77,103.0	30,028.3	7,507.1	625.590	52,430.0	5,355.4	144,706.9	97,632.2
2030	147742	48016.2	77,103.0	29,086.8	7,271.7	605.976	52,430.0	4,413.9	144,706.9	96,690.7
2031	150697	48976.5	77,103.0	28,126.5	7,031.6	585.969	52,430.0	3,453.6	144,706.9	95,730.4
2032	153711	49956.0	77,103.0	27,147.0	6,786.7	565.562	52,430.0	2,474.0	144,706.9	94,750.9
2033	156785	50955.1	77,103.0	26,147.9	6,537.0	544.747	52,430.0	1,474.9	144,706.9	93,751.8
2034	159921	51974.2	77,103.0	25,128.8	6,282.2	523.516	52,430.0	455.8	144,706.9	92,732.7
2035	163119	53013.7	77,103.0	24,089.3	6,022.3	501.860	52,430.0	(583.7)	144,706.9	91,693.2
2036	166382	54074.0	77,103.0	23,029.0	5,757.3	479.771	52,430.0	(1,644.0)	144,706.9	90,632.9
2037	169709	55155.5	77,103.0	21,947.5	5,486.9	457.240	52,430.0	(2,725.4)	144,706.9	89,551.4
2038	173103	56258.6	77,103.0	20,844.4	5,211.1	434.259	52,430.0	(3,828.5)	144,706.9	88,448.3
2039	176565	57383.8	77,103.0	19,719.2	4,929.8	410.818	52,430.0	(4,953.7)	144,706.9	87,323.2
2040	180097	58531.4	77,103.0	18,571.6	4,642.9	386.908	52,430.0	(6,101.4)	144,706.9	86,175.5
2041	183699	59702.1	77,103.0	17,400.9	4,350.2	362.520	52,430.0	(7,272.0)	144,706.9	85,004.8
2042	187373	60896.1	77,103.0	16,206.9	4,051.7	337.644	52,430.0	(8,466.1)	144,706.9	83,810.8
2043	191120	62114.0	77,103.0	14,989.0	3,747.2	312.270	52,430.0	(9,684.0)	144,706.9	82,592.9
2044	194942	63356.3	77,103.0	13,746.7	3,436.7	286.389	52,430.0	(10,926.3)	144,706.9	81,350.6
2045	198841	64623.4	77,103.0	12,479.6	3,119.9	259.991	52,430.0	(12,193.4)	144,706.9	80,083.5
2046	202818	65915.9	77,103.0	11,187.1	2,796.8	233.065	52,430.0	(13,485.9)	144,706.9	78,791.0
2047	206875	67234.2	77,103.0	9,868.8	2,467.2	205.600	52,430.0	(14,804.2)	144,706.9	77,472.7
2048	211012	68578.9	77,103.0	8,524.1	2,131.0	177.585	52,430.0	(16,148.9)	144,706.9	76,128.0
2049	215232	69950.5	77,103.0	7,152.5	1,788.1	149.011	52,430.0	(17,520.4)	144,706.9	74,756.4
2050	219537	71349.5	77,103.0	5,753.5	1,438.4	119.865	52,430.0	(18,919.5)	144,706.9	73,357.4

Year	Population	Rice Consumption (Ton)	WITHOUT FLOODING				WITH FLOODING			
			Production (Ton)	Available Rice for cash (Ton)	Income from Rice (USD)	Income per Month (USD)	Rice Production	Rice Deficit (Ton)	On-Farm Reservoir 176%	
									Rice Production (Ton)	Rice Deficit (Ton)
2051	223928	72776.5	77,103.0	4,326.5	1,081.6	90.136	52,430.0	(20,346.4)	144,706.9	71,930.4
2052	228406	74232.0	77,103.0	2,871.0	717.7	59.812	52,430.0	(21,802.0)	144,706.9	70,474.9
2053	232974	75716.7	77,103.0	1,386.3	346.6	28.882	52,430.0	(23,286.6)	144,706.9	68,990.3
2054	237634	77231.0	77,103.0	(128.0)	(32.0)	(2.666)	52,430.0	(24,800.9)	144,706.9	67,475.9
2055	242386	78775.6	77,103.0	(1,672.6)	(418.2)	(34.846)	52,430.0	(26,345.6)	144,706.9	65,931.3
2056	247234	80351.1	77,103.0	(3,248.1)	(812.0)	(67.669)	52,430.0	(27,921.1)	144,706.9	64,355.8
2057	252179	81958.1	77,103.0	(4,855.1)	(1,213.8)	(101.149)	52,430.0	(29,528.1)	144,706.9	62,748.8
2058	257222	83597.3	77,103.0	(6,494.3)	(1,623.6)	(135.298)	52,430.0	(31,167.3)	144,706.9	61,109.6
2059	262367	85269.2	77,103.0	(8,166.2)	(2,041.6)	(170.130)	52,430.0	(32,839.2)	144,706.9	59,437.7
2060	267614	86974.6	77,103.0	(9,871.6)	(2,467.9)	(205.659)	52,430.0	(34,544.6)	144,706.9	57,732.3
2061	272967	88714.1	77,103.0	(11,611.1)	(2,902.8)	(241.898)	52,430.0	(36,284.1)	144,706.9	55,992.8
2062	278426	90488.4	77,103.0	(13,385.4)	(3,346.4)	(278.863)	52,430.0	(38,058.4)	144,706.9	54,218.5
2063	283994	92298.2	77,103.0	(15,195.2)	(3,798.8)	(316.566)	52,430.0	(39,868.1)	144,706.9	52,408.7
2064	289674	94144.1	77,103.0	(17,041.1)	(4,260.3)	(355.024)	52,430.0	(41,714.1)	144,706.9	50,562.8
2065	295468	96027.0	77,103.0	(18,924.0)	(4,731.0)	(394.250)	52,430.0	(43,597.0)	144,706.9	48,679.9
2066	301377	97947.6	77,103.0	(20,844.6)	(5,211.1)	(434.262)	52,430.0	(45,517.5)	144,706.9	46,759.3
2067	307405	99906.5	77,103.0	(22,803.5)	(5,700.9)	(475.073)	52,430.0	(47,476.5)	144,706.9	44,800.4
2068	313553	101904.6	77,103.0	(24,801.6)	(6,200.4)	(516.701)	52,430.0	(49,474.6)	144,706.9	42,802.3
2069	319824	103942.7	77,103.0	(26,839.7)	(6,709.9)	(559.161)	52,430.0	(51,512.7)	144,706.9	40,764.2
2070	326220	106021.6	77,103.0	(28,918.6)	(7,229.6)	(602.471)	52,430.0	(53,591.6)	144,706.9	38,685.3
2071	332745	108142.0	77,103.0	(31,039.0)	(7,759.8)	(646.646)	52,430.0	(55,712.0)	144,706.9	36,564.9
2072	339400	110304.9	77,103.0	(33,201.9)	(8,300.5)	(691.705)	52,430.0	(57,874.8)	144,706.9	34,402.0
2073	346188	112511.0	77,103.0	(35,408.0)	(8,852.0)	(737.666)	52,430.0	(60,080.9)	144,706.9	32,196.0
2074	353111	114761.2	77,103.0	(37,658.2)	(9,414.5)	(784.545)	52,430.0	(62,331.1)	144,706.9	29,945.7
2075	360174	117056.4	77,103.0	(39,953.4)	(9,988.4)	(832.363)	52,430.0	(64,626.4)	144,706.9	27,650.5
2076	367377	119397.5	77,103.0	(42,294.5)	(10,573.6)	(881.136)	52,430.0	(66,967.5)	144,706.9	25,309.4
2077	374725	121785.5	77,103.0	(44,682.5)	(11,170.6)	(930.885)	52,430.0	(69,355.4)	144,706.9	22,921.4
2078	382219	124221.2	77,103.0	(47,118.2)	(11,779.5)	(981.629)	52,430.0	(71,791.2)	144,706.9	20,485.7
2079	389863	126705.6	77,103.0	(49,602.6)	(12,400.7)	(1,033.388)	52,430.0	(74,275.6)	144,706.9	18,001.3
2080	397661	129239.7	77,103.0	(52,136.7)	(13,034.2)	(1,086.182)	52,430.0	(76,809.7)	144,706.9	15,467.2
2081	405614	131824.5	77,103.0	(54,721.5)	(13,680.4)	(1,140.032)	52,430.0	(79,394.5)	144,706.9	12,882.4
2082	413726	134461.0	77,103.0	(57,358.0)	(14,339.5)	(1,194.959)	52,430.0	(82,031.0)	144,706.9	10,245.9
2083	422001	137150.2	77,103.0	(60,047.2)	(15,011.8)	(1,250.984)	52,430.0	(84,720.2)	144,706.9	7,556.7
2084	430441	139893.2	77,103.0	(62,790.2)	(15,697.6)	(1,308.130)	52,430.0	(87,463.2)	144,706.9	4,813.7
2085	439050	142691.1	77,103.0	(65,588.1)	(16,397.0)	(1,366.419)	52,430.0	(90,261.1)	144,706.9	2,015.8
2086	447831	145544.9	77,103.0	(68,441.9)	(17,110.5)	(1,425.873)	52,430.0	(93,114.9)	144,706.9	(838.0)
2087	456787	148455.8	77,103.0	(71,352.8)	(17,838.2)	(1,486.517)	52,430.0	(96,025.8)	144,706.9	(3,748.9)
2088	465923	151424.9	77,103.0	(74,321.9)	(18,580.5)	(1,548.374)	52,430.0	(98,994.9)	144,706.9	(6,718.0)

Year	Population	Rice Consumption (Ton)	WITHOUT FLOODING				WITH FLOODING			
			Production (Ton)	Available Rice for cash (Ton)	Income from Rice (USD)	Income per Month (USD)	Rice Production	Rice Deficit (Ton)	On-Farm Reservoir 176%	
									Rice Production (Ton)	Rice Deficit (Ton)
2089	475241	154453.4	77,103.0	(77,350.4)	(19,337.6)	(1,611.467)	52,430.0	(102,023.4)	144,706.9	(9,746.5)
2090	484746	157542.5	77,103.0	(80,439.5)	(20,109.9)	(1,675.823)	52,430.0	(105,112.5)	144,706.9	(12,835.6)
2091	494441	160693.4	77,103.0	(83,590.4)	(20,897.6)	(1,741.466)	52,430.0	(108,263.3)	144,706.9	(15,986.4)
2092	504330	163907.2	77,103.0	(86,804.2)	(21,701.1)	(1,808.421)	52,430.0	(111,477.2)	144,706.9	(19,200.3)
2093	514417	167185.4	77,103.0	(90,082.4)	(22,520.6)	(1,876.716)	52,430.0	(114,755.3)	144,706.9	(22,478.5)
2094	524705	170529.1	77,103.0	(93,426.1)	(23,356.5)	(1,946.377)	52,430.0	(118,099.0)	144,706.9	(25,822.2)
2095	535199	173939.7	77,103.0	(96,836.7)	(24,209.2)	(2,017.430)	52,430.0	(121,509.6)	144,706.9	(29,232.7)
2096	545903	177418.4	77,103.0	(100,315.4)	(25,078.9)	(2,089.905)	52,430.0	(124,988.4)	144,706.9	(32,711.5)
2097	556821	180966.8	77,103.0	(103,863.8)	(25,966.0)	(2,163.830)	52,430.0	(128,536.8)	144,706.9	(36,259.9)
2098	567957	184586.2	77,103.0	(107,483.2)	(26,870.8)	(2,239.232)	52,430.0	(132,156.1)	144,706.9	(39,879.2)
2099	579317	188277.9	77,103.0	(111,174.9)	(27,793.7)	(2,316.143)	52,430.0	(135,847.8)	144,706.9	(43,571.0)
2100	590903	192043.4	77,103.0	(114,940.4)	(28,735.1)	(2,394.592)	52,430.0	(139,613.4)	144,706.9	(47,336.5)

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