DROUGHT, DROUGHT VULNERABILITY AND ADAPTATION POLICY IN CAMBODIA WITH REFERENCE TO THE FARMING SECTOR

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2015

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A thesis submitted for the degree of Doctor of Philosophy

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Adelaide, December 11, 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Farmers in Cambodia face two major natural hazards – floods and droughts. Millions of people are affected by these hazards on a regular basis and millions of hectares of rice paddies are regularly destroyed. Drought is less well understood than flooding, yet it accounted for about a fifth of total rice losses from 1997 to 2001. The importance of that figure is underlined by the fact that rice cultivation is the main economic activity in Cambodia, and that the government has prioritised agricultural development as a critical component in its poverty reduction and export commodity programs.

While measures have been employed to reduce flood and drought impacts, these two natural hazards are still serious issues and compromise rural household livelihoods as well as impacting on the national economy. Research on drought in Cambodia is still limited, and the methods used to conduct drought assessment are based on locality. The overall aim of the research is to improve our understanding of the impacts of drought on rice production in Cambodia and how these impacts of drought might be alleviated.

The Standardized Precipitation Index (SPI) was evaluated and found to be the most appropriate index to identify drought and non–drought years in the existing records. Moreover droughts identified this way tied in with variations in the regional monsoonal climatology. The droughts were also statistically related to harvest losses. As there are causal linkages between drought (based on SPI values and climate science) and paddy rice damage, it is argued that SPI can be used to estimate the degree of severity of drought in Cambodia and to monitor droughts.

Economic analysis was designed to estimate the cost of droughts under business–as–usual and (re)building water infrastructure (i.e. irrigation systems) scenarios. Risk–based cost and benefit analysis was used and the expected costs were calculated for drought impacts. The primary argument is that the costs of the business–as–usual scenario are higher than those for building irrigation systems to secure water supplies for multiple cropping rice farming systems. The importance of multiple cropping is emphasised in the drought analysis and will be essential in helping farmers minimise the effects of drought on rice cultivation.

In terms of the policy implications, arguments are constructed based on the current threat of droughts in the context of climate change and agricultural development. The capacity of farmers to

adapt to climate change and how to address those natural hazards like drought and climate are evaluated at the national policy level.

The thesis concludes that drought monitoring and mitigation measures must be taken from the local (commune) to national level.

DECLARATION

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Nyda Chhinh

Adelaide, December 11 2015

ACKNOWLEDGEMENTS

I owe my research, remote sensing, data analysis skills and knowledge to Professor Andrew Millington, who always encourages, helps, advises, and gives suggestions. Without him, this achievement would not have occurred. I would also like to thank Dr. Simon Benger and Dr. Cecile Cutler for guidance, and kind editing of this thesis. I also appreciate the knowledge gained through Stephen Fildes during Remote Sensing Topics. Thanks are due to the staff of the School of the Environment who have given me assistance during this thesis such as Robert Keane. My office mates: Joni, Thi Thanh Trang Pham and Darrell House have been sources of knowledge, skills, sadness and joys during the cultivation of my PhD degree.

I am doing this PhD under the Higher Education Quality and Capacity Improvement Project (HEQCIP) scheme through the Department of Higher Education of the Ministry of Education, Youth and Sport, Cambodia. I am grateful to the project staff and the assistance provided to me.

This work has many external contributors. The generosity of Mr. Chea Bora from Department of Water Resource and Meteorology of Kampong Speu Province who shared rainfall data; the International Development Research Centre (IDRC) of Canada and Economy and Environment Program for Southeast Asia (EEPSEA) who provided me with a grant to conduct research related to the economic study and who partly supported this thesis; Mr. Cheb Hoeurn, Mr. Kong Sopheak and Ms. Sen Rineth who helped me with gathering data; and the Royal University of Phnom Penh where I work as a Lecturer.

My family is also the source of my knowledge. I would like to thank my wife, Meas Ottany. She tirelessly gives me her time, challenges me with the game of mind and has supported through my studies. She always says: your job is to study. My parents, Sram Chhinh and Lay Yi, are my beloved persons whom I thank greatly.

Last but not least, my thank is to Ms Kristy Johns. She smiles at me, she shares laughter; and she is also my dictionary as well. Any words that I do not know for sure, she can tell me in plain English. Flinders University’s librarians are also very helpful – thank you.

ABBREVIATIONS

ADB	Asian Development Bank
ADPC	Asian Disaster Preparedness Center
ADRC	Asian Disaster Reduction Center
CEDAC	Centre d’Etude et de Développement Agricole Cambodgien
CRED	Center for Research on Epidemiology of Disaster
DA	Department of Agriculture
DEM	Digital Elevation Model
EM–DAT	Emergency Event Database
ENSO	El Niño–Southern Oscillation
FAO	Food and Agriculture Organization
FWUC	Farmer Water User Committees
GDP	Gross and Domestic Products
GHG	Greenhouse Gas
Ha	Hectare
IPCC	Intergovernmental Panel for Climate Change
JICA	Japan International Cooperation Agency
KPS	Kampong Speu
LULC	Land Use and Land Cover
MAFF	Ministry of Agriculture, Forestry, and Fisheries
mm	Millimeters
MODIS	Moderate Resolution Imaging Spectroradiometer
MoE	Ministry of Environment
MoWRAM	Ministry of Water Resources and Meteorology
MRC	Mekong River Committee
MRD	Ministry of Rural Development
NAPA	National Adaptation Plan of Action
NCDM	National Committee for Disaster Management
NDVI	Normalized Different Vegetation Index
NIS	National Institute of Statistics
NSDP	National Strategic Development Plan
NSYB	National Statistics Year Book
OECD	Organisation for Economic Co–operation and Development
ONI	Ocean Niño Index
RGC	Royal Government of Cambodia
SNAP	Strategic National Action Plan
SPI	Standardized Precipitation Index
SRI	System Rice Intensification
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations Secretariat of the International Strategy for Disaster Reduction
WB	World Bank
WCDR	World Conference on Disaster Reduction
WFP	World Food Program

CURRENCY EXCHANGE RATE 1960–2015

US dollar is used in parallel with the local currency, the Riel. The exchange rate between the USD and Riels is shown below. The Cambodian riel is not negotiable in international markets as of 2015.

Year	1960	1980	1987	1990	1995	2000	2005	2010	2015
USD 1.00	35	4	100	426	2,450	3,840	4,092	4,184	4,056

Source: World Bank Data Book (http://data.worldbank.org/country/cambodia)

CHAPTER 1: INTRODUCTION

1.1. Introduction

Droughts compound the socio–economic challenges facing developed and developing economies. They lead to increase food prices (Mitchell 2008; Von Braun 2008); food insecurity (Hossain & Green 2011; Mittal 2009; Kiros 1991); poverty and famine (Buckley *et al.* 2010); and loss of jobs (Carlton 2014; Horridge *et al.* 2005). Droughts have led to civil conflicts (Collier 2007; Pinstrup–Andersen *et al.* 1999); crime and violence (Theisen 2012); psychological stress (Dean & Stain 2010); and migration (Findley 1994). Last but not least, droughts are a form of environmental degradation (Bond *et al.* 2008; Dale *et al.* 2001; Tilman & El Haddi 1992).

Two factors trigger drought–related disasters: (i) the vulnerability of human, socio–economic and political systems, and (ii) climate variability. Vulnerabilities inherent in socio–economic and political systems have been recorded by Turner *et al.* (2003) and Adger (2006), whereas an individual's capacity to cope with drought has been noted by Smit *et al.* (2000) and Smith (1996). Climate variability is driven by global, regional, and local meteorological and geophysical characteristics. For example, climate variations in Cambodia have been attributed to modulations in the El Niño Southern Oscillation (ENSO), the Indian Ocean Dipole (IOP), and influence of the Tibet Plateau (Huang *et al.* 2007; Ding & Chan 2005; Hsu 2005; Chen & Yoon 2000).

The United Nations International Strategy for Disaster Reduction (UNISDR) has proposed a Drought Reduction Framework to manage drought risk. This framework lists activities to reduce drought vulnerability including the establishment of drought early warning systems (UNISDR 2007). More recently, IPCC (2014) have proposed a similar framework to assess future climate risk, as illustrated in their Figure SM.1, and this, in itself, can be seen as an evolutionary step beyond the UNISDR framework. Wilhite *et al.* (2014) stressed the need for a procedure to activate national drought policies (see Chapter 6). This research is a Cambodian response to their call.

The remainder of this chapter provides background information on drought and agriculture in Cambodia; it describes the study area – Kampong Speu province; introduces the research aims and objectives; and outlines the structure of the thesis.

1.2. Problem Statement

There are two major climate hazards in Cambodia – floods and droughts. The latter are significantly under–researched compared with the former (Te 2007; Helmers & Jegillos 2004), though recent drought research covers Cambodia as part of broader Southeast Asia studies. Son *et al.* (2012) computed normalised difference vegetation indices and the temperature vegetation dryness indices from remotely sensed data for the Mekong Delta. Adamson and Bird (2010) analysed droughts and floods from records of rainfall and river discharges in the Mekong Basin with a focus on Cambodia, Laos, Thailand and Vietnam. Nguyen and Shaw (2011) studied drought at the community level focusing on social perspectives and how people cope with drought. However, earlier research in Cambodia by the Ministry of Environment (2001), the World Food Program (2003) and Steyaert *et al.* (1981) were not comprehensive enough to understand how drought manifested itself in Cambodia or how mitigation or adaption played out at either the household or national levels.

Cambodia ranks highly amongst the drought–prone countries in Asia–Pacific region (Steyaert *et al.* 1981). Pandey *et al.* (2007) report on drought occurrences in the region from 1981 to 2004. During this period, Cambodia experienced drought eight times, while the three most affected countries experienced drought 11 to 15 times. However, they did not record the 1982–83 drought, which was related to a very strong El Niño event and led to extensive food shortages. The Ministry of Agriculture, Forestry, and Fisheries (2010) also reported droughts in 1988, 1991, 1992, and 1998. Pandey *et al.* (2007) did not record these either and, therefore, during the 1981–2004 time frame Cambodia suffered 13 droughts; elevating its status as a drought–prone nation.

Climatic hazards greatly impact on Cambodian agriculture. In Prime Minister Hun Sen's declaration on disasters in 2002, he pointed out that the country had experienced the most severe flooding in 70 years in 2001 when 347 people died (70 percent of whom were children) and damages totalled around USD 150 million (ADRC 2001). In 2001, USD 36 million in damage and 61 lives were lost due to climate–related phenomena (National Committee for Disaster Management 2008). The following year, floods devastated the country again. Although no deaths were reported that year, Cambodia experienced rice shortages because 63 percent of the agricultural land had been flooded or experienced drought (Asian Disaster Preparedness Center 2002). Floods, droughts and climate–related insect outbreaks impact on rural livelihoods, and in the agricultural sector alone, floods and

droughts accounted for 70 percent and 20 percent of all damage respectively between 1997 and 2001 (Ministry of Environment 2001).

IPCC (2007) and Field and Van Aalst (2014) warn that future climate change is inevitable, and that countries and people globally have to adapt to the changing climate. What might this mean for Cambodia? According to the First and Second (draft) National Communications with the UNFCCC, the greatest concerns for Cambodia are floods (commonly encountered along the Mekong and around the Tonle Sap Lake) and drought (which is more widespread across the country) (Ministry of Environment 2009; 2002).

1.3. Research Aims

The overall aim of the research is to improve our understanding of the impacts of drought on rice production in Cambodia and how these impacts of drought might be alleviated. This is achieved by focusing in detail on Kampong Speu (KPS) Province (Section 1.6). There are three research objectives:

1. to quantify drought severity in KPS;
2. to estimate the expected costs of droughts in Kampong Speu Province; and
3. to evaluate the potential for solutions to drought related disasters through monitoring and/or mitigating droughts in KPS and, more broadly, in Cambodia.

1.4. Significance of the Research

It is clear that droughts can significantly affect rice production in Cambodia and therefore impact on the entire rice supply chain from feeding rice–producing households through to food security in the nation’s cities, to Cambodia’s position as a rice exporter and, hence, global food security. Therefore droughts in Cambodia can affect food prices and food security at a wide range of geographical scales. The rice sector provides the nation with the potential to participate in regional and global trade. Cambodian rice is acknowledged among the best in the world. For example, Cambodian jasmine rice won the ‘World’s Best Rice Award for 2012’ ahead of Thai rice varieties at the World Rice Conference (Bali, September 2012) organised by The Rice Trader (Khoun 2012). This enhanced profile cements the government’s objective of expanding export markets for jasmine rice, which is not photosensitive and can be harvested in 120 days, in addition to other varieties. The target is to export one million tonnes by 2015 compared with an official figure of 13,000 tonnes in 2009 (Royal

Government of Cambodia 2010b; Ministry of Environment 2005b). The objective is feasible if historical precedents are considered. Cambodia used to be the fifth largest rice exporter by volume in the global marketplace between 1950 and 1964 (Dawe 2002) but had dropped away by 2002 (Gulati & Narayanan 2003) (see Section 1.5).

It should be noted that the impact of drought in the rural sector extends beyond the concerns outlined above. The government is actively developing the agricultural sector so that it can also supply raw materials – particularly cotton and rubber – to the economically important textile, apparel and footwear industries (CDRI 2007).

1.5. A Brief History of Rice Cultivation in Cambodia

Rice production can be described chronologically in the following eras: (i) the Angkorian period (889–1434); (ii) the Post–Angkorian (1432–1863); (iii) the French protectorate (1863–1953); (iv) the Sihanouk regime (1953–1970); (v) the 1970–1979 civil war; and (vi) under the current government (1979–present).

The Angkorian period (which is also known as the Khmer Empire) is named after the great civilisation that developed on the fertile soils around the Great Lake of the Tonle Sap (Herz 1958). Rice production reached a peak at that time due to the establishment of a very efficient irrigation system (Audric 1972) that was introduced to Cambodia from India over 1500 years ago (Chandler 1983). Some of the physical infrastructure from that period is still in operation. It can be assumed that during the Angkorian period rice production contributed significantly to the prosperous imperial economy. Buckley *et al.* (2010) argue that the fall of the Angkor Empire can be attributed to a long, high–intensity drought, which severely impacted on water supply and agricultural production. The post–Angkorian period was marked by ongoing conflicts with neighbouring countries and, according to Tully (2005), rice production decreased as the irrigation systems fell into disrepair from the 15th century onwards. There is also evidence that the Siamese may have sabotaged the irrigation systems. Urban rice supply chains must have been stretched because when Ponhea Yat moved the capital of Cambodia to Srei Santhor in 1432 (and then to Phnom Penh) no irrigation systems were developed to support these cities.

During the French protectorate (1863–1953), the pre–occupation of the metropolitan power was on the production of export crops, particularly cotton, with little attention being paid to domestic

food crops (Tully 2005). From 1953 to 1970, under the Sihanouk regime, the importance of rice rose again as it became the core of economic development. Yet Slocomb (2010) argues that Cambodia failed to develop the sector during this 18–year period, and that this led to increasing disparities in living standards between city dwellers and those in the countryside. The area of paddy rice cultivated in Cambodia in 1963 was 2.2 million ha, with a yield of 1.1 tonne/ha nationally (Nesbitt 1997). By 1970 production had reached 3.8 million tonnes with the development of irrigation systems and the application of pesticides and fertilizers (ibid). This was said to be one the greatest achievements in Cambodian history. The national rice production system was disrupted again during the civil war of the 1970s. Under the Khmer Republic and Khmer Rouge regimes (or Pol Pot regimes), Cambodia experienced massive internal conflict and associated mass starvation (Tully 2005; Chandler 1983). While the Khmer Republic was totally dependent on foreign aid (Raymond 1996), the Khmer Rouge regime attempted to turn the country into a utopian socialist society based on an agrarian economy. However, the promotion of rice as the basis of the socialist economy failed. This resulted in widespread famine and starvation. From 1975 to 1979, the Khmer Rouge regime attempted to increased rice production by harvesting two or more crops each year through the introduction of high yielding varieties, by constructing a one–square kilometre grid irrigation systems, and by forcing the urban population into the countryside to farm. Yields of at least 3 tonnes/ha were anticipated. Although agricultural records are poor for this period, it is estimated that yields were in actual fact very low. Due to the lack of further investments in technology and maintenance, the extensive irrigation infrastructure built during the Khmer Rouge period was barely functioning by 1983 (Halcrow 1994). While the failures in rice production this time were mainly a consequence of the political economy during the Pol Pot regime, droughts such as the ENSO event in 1977–1978, will have also contributed to low production.

Agricultural development since 1979 can be divided into two periods: 1979–1992 and 1993–present. Internal conflicts in Cambodia remained part of the political milieu between 1979 and 1993 with many parts of the country under the control of various rebel groups. Raymond (1996) observes that rice yield during that period ranged from less than one tonne to around 1.3 tonne/ha. Not surprisingly, no significant or successful developments to increase rice production were carried out at this time. Before the 1993 general election, the government focused on socio–economic rehabilitation and development (SRD) based on a centrally planned economy. The Ministry of Planning prepared two five–year programs of SRD for 1986–1990 and 1991–1995 (National Institute

of Statistics 2012). The shift to a market based economy started in 1995. This has been guided by a series of strategic plans: Socio–Economic Development Plans (SEDP) I (1996–2000), SEDP II (2001–2005), the National Poverty Reduction Strategy (2003–2005), the National Strategic Development Plan (NSDP) (2006–2010), the NSDP Update (2009–2013), and the NSDP (2014–2018). These plans derive from two broad political platforms of government known as the Triangular Strategy and the Rectangular Strategy. Both focus on poverty reduction, with the agricultural sector being the central tenet of economic growth and improvements in rural livelihoods. The development of irrigation infrastructure to supplement wet season rice cultivation on small farms is stressed highly in these policies, which had an overarching target of increasing the area under rice from 407,000 ha (1998) to 650,000 ha (2010) (Royal Government of Cambodia 2010b).

1.6. Kampong Speu Province

Kampong Speu (KPS) province (Figure 1.1) was selected for this research for three reasons. First, the province has higher vulnerability to drought (and flooding) than other provinces (Chhinh 2014). In a climate change vulnerability assessment for Cambodia, KPS was found to be highly susceptible to climate change because of its high overall population, high rate of economic development, and prevalence of social issues (Yusuf & Francisco 2010). In response to severe droughts and floods, millions of dollars have been spent on a regular basis in KPS to protect people's livelihoods and infrastructure.

Second, forest cover in the province has decreased from approximately 60 to 30 percent between 1970 and 2013 (Open Development Cambodia n.d). The Mekong River Commission has indicated that the KPS watershed is at a critical stage because of upper catchment forest loss. Changes in land cover coupled with the sandy texture of the majority of soils and rainfall variability have led to high rates of soil erosion. The climate change and land cover change nexus means that farmers will be exposed to greater losses in agricultural production in the future. In addition groundwater levels will decline, and human and animal health risk will increase due to siltation and contaminated runoff.

Finally, the combination of droughts, floods, forest loss and land degradation means that the incidence of poverty is higher amongst the rural poor than in other provinces. The majority of farmers are, on average, heads of household with 5.5 people and farms less than a hectare of paddy rice. While paddy is the staple, livestock are also integral to the people livelihoods. Changes in

climate will impact on their livelihoods. Unsurprisingly, KPS has a higher level of out migration and more social issues than its neighbouring provinces.

The province is one of 25[1] in Cambodia. It is located about 48 km west of Phnom Penh, It covers 6,534 km^2 and it is administratively divided into one town (Krong Chbar Morn) and seven districts (Figure 1.1). It is further divided into 87 communes and 1,308 villages (National Institute of Statistics 2008b).

From east to west the topography ranges from extensive lowland paddy fields through a lowland/upland mosaic to forested uplands. Cambodia's highest mountain – Phnom Aural (1,813 m.a.s.l.) – is located in the northwest of the province. The average annual maximum temperature is approximately 27°C and the minimum about 16°C. December and January are the coolest months, while the hottest is April when maximum temperatures reach 35°C. The province is influenced strongly by the Southeast Asia monsoon, as well as by other climate systems including the Indian Summer Monsoon, the East Asian Summer Monsoon, and the Western North Pacific Summer Monsoon (see Chapter 3 for more details).

Most of the province is located in the Prek Thnot River catchment (Figure 1.1) – one of the most significant hydrological systems in Cambodia. The upper catchment comprises steep forested slopes, while in lower elevations most of the forest has been cleared for rice cultivation. The areas located close to the river in the lower catchment are highly vulnerable to floods and droughts (Chann & Kong 2014). The southern part of the province is located within the Mekong Delta and the northern part is in the Boribo River catchment.

[1] In 2014, Kampong Cham Province was split into two provinces.

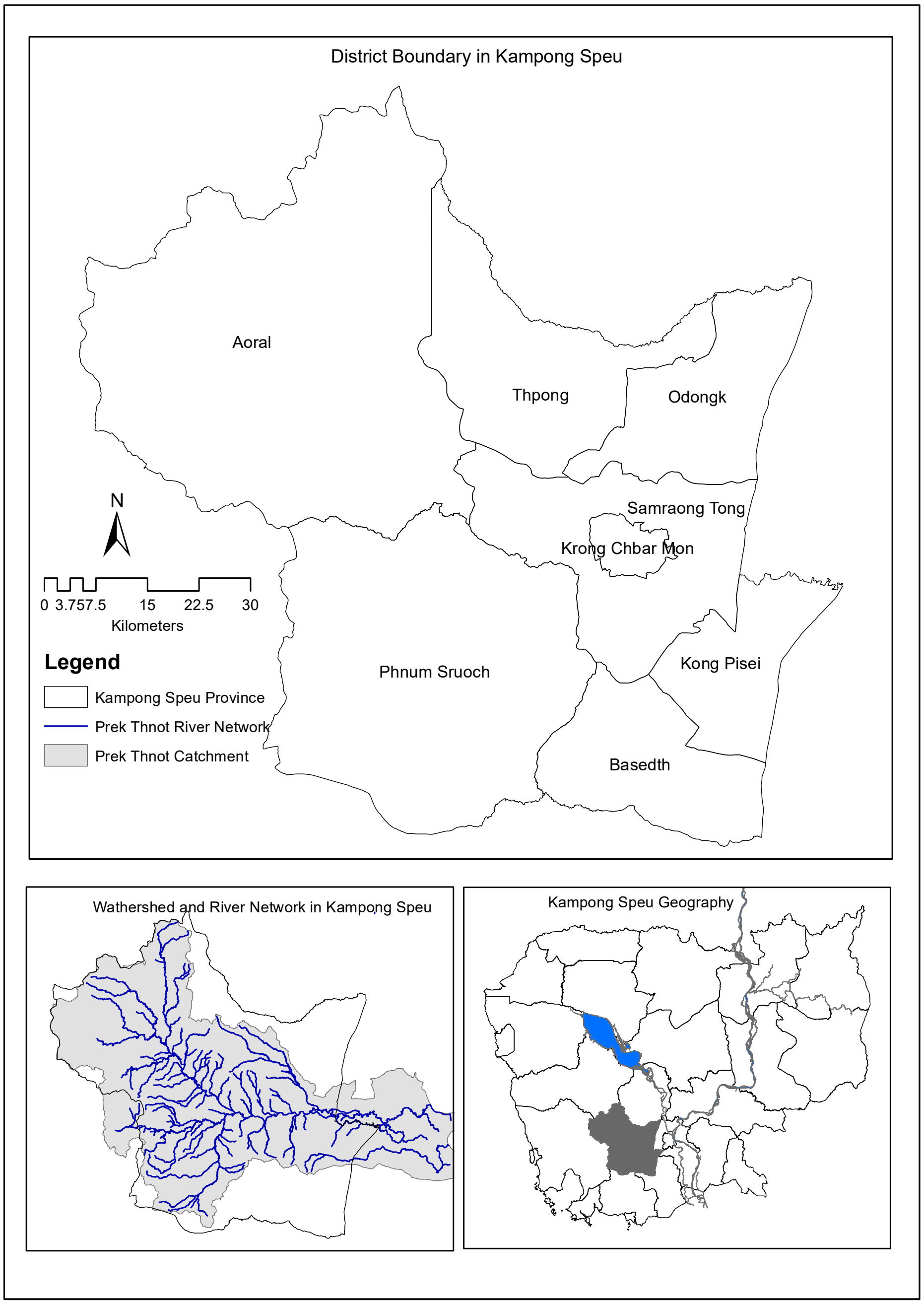


Figure 1.1: Study site and its hydrological and geographical characteristics.

Sources: Administrative boundary is from the National Geographic Department of Cambodia; Watershed and River Network in Kampong Speu is from Mekong River Commission.

In 2012, the population of KPS was reported about 812,290 people. Approximately 40 percent are under 18 years of age and the average annual population growth rate is 1.19 percent (in 2008). The population density is 116 persons/km^2 compared with the national average of 75 persons/km^2 (National Committee for Sub–National Democratic Development 2012). About 68 percent of people

farm, while the remainder are employed in the textile and garment industries. In addition to income provided from the main crops – rice, tree fruits, cassava and cashews (National Institute of Statistics 2013) – there have been attempts at diversification through the sale of palm sugar, handicrafts and non–timber forest products. Nonetheless, in common with other provinces in Cambodia, rural communities are highly dependent on agricultural production as their main income source and, in turn, farm production is highly dependent on seasonal rainfall.

1.7. Thesis Organisation

The thesis is structured around six chapters. The first provides the rationale and background to the research. Some of the material in this chapter is expanded on in the literature review (Chapter 2) as well as other chapters. Chapter 3 analyses meteorological data to assess drought severity, and links this to rice damage and regional climate variability. The next chapter (Chapter 4) examines drought impact on paddy production at the household level. This aspect of the research compares rain–fed and supplementary irrigation systems, and estimates the cost of drought and how irrigation facilities can reduce these costs. Chapter 5 discusses how drought is addressed at local to national levels. The findings from the previous three chapters are synergised in Chapter 6, which weaves threads of science, economics and policy together, and analyses what can be done to reduce the impacts of natural disasters more generally in Cambodia. The thesis culminates with a short conclusion and recommendations.

This list of chapters above shows that three distinct threads have been brought together to address this problem and to provide a Cambodian response to Wilhite et al.'s (2014) call for research that will lead to the formulation of national-level drought policies. Shaw (2014) argued that disaster recovery is a development opportunity and that recovery from drought should be based on local needs, education, and technology. In the vein of Shaw's (2014) argument, this PhD 'by publication' around three distinct peer reviewed publications leads to climatology, economic and policy formulation being stressed. This is perhaps wise given the fundamental nature of this research in the Cambodian environment at this time, where developing basic levels of knowledge and understanding around the key aspects of drought is an essential pre-cursor to developing a more nuanced understanding drought in the country where more complex research methods can be applied and their results understood.

Much of this research has published during the course of my PhD in referenced book Chapter and peer reviewed scientific journals. Chapters 3, 4 and 5 are refereed publications (Table 1.1).

Table 1.1: Details of publications.

Chapter	Original publication details
3	Chhinh, N & Millington, A. C 2015, Drought monitoring for rice production in Cambodia. *Climate,* vol. 3, no. 4, pp. 792–811.
4	Chhinh, N, Cheb, H & Heng, N 2014, Drought Risk in Cambodia: Assessing Costs and a Potential Solution. *Asian Journal of Agriculture and Development,* vol. 11, no. 2, pp. 1–16.
5	Chhinh, N 2014, Climate change adaptation in agriculture in Cambodia, In: *Adaptation to Climate Change in Asia,* Vachani, S., (ed.), Edward Elgar, London, pp. 163–182.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

"We may say truthfully that we scarcely know a drought when we see one" – (Tannehill 1947, p. 15).

Humankind has always lived with flood and drought. In the past, people believed that these hazards were the curses of Gods and Goddesses (Heathcote 2013; Ifejika *et al.* 2008; Slegers 2008). In terms of the scientific process of drought, Tannehill (1947) classified drought as 'Synoptic Climatology' in which he combined climate and meteorology. The above quote suggests that people historically misunderstood drought, but Tannehill argued that 'drought can be measured and studied and predicted with increasing precision in our observations of the sun and the upper air and the oceans' (1947, p. 231). The current and prominent focus of the literature related to drought is on *risk* and *vulnerability* which involves more than the science of climatology. Risk refers to the probability of drought occurrence (including severity) and potential damage (Blaikie *et al.* 1994; Burton 1993). Vulnerability of people is linked with *hazard exposure*, *sensitivity*, and *adaptive capacity* (Hinkel 2011; Adger 2006; McCarthy *et al.* 2001). Drought is also examined by economists, sociologists, environmentalists, and others implying that drought is complicated and lends itself to many disciplines. For this reason there are many definitions of drought, and they are not universal (Wilhite & Glantz 1985). A central concept of drought, however, relates to its impacts and how to mitigate and/or adapt to it.

Drought impacts are different from household to household, within regions, and between countries. 'Droughts are the deadliest of the four natural hazard categories which include earthquakes, floods, and storms' (United Nations 2010, p. 10). In a developed country such as the United States, drought impacts in California in 2014 alone cost about USD 2.2 billion and cut employment by about 3.8 percent (Carlton 2014). For less developed countries such as Zimbabwe or Malawi, drought can kill many people and cause the collapse of social and political structures (Clemens & Moss 2005). However, the death toll from drought declined from 3 million people in 1928 in China alone to about 100 thousand worldwide in the 1980s (EM–DAT 2012). The most recent deadliest drought hit the Horn of Africa in 2011 and caused tens of thousands of deaths (BBC 2012). Besides the deaths caused by drought, Chapman (1994, p. 123) classified drought impacts under three types: economic, social, and environmental impacts of drought. Scholars have examined all aspects of drought

impacts at a range of spatial and temporal scales. This chapter reviews the literature on drought in relation to:

1. theories developed for drought assessment;
2. empirical studies of drought; and
3. knowledge and research gaps in the implementation of drought mitigation and/or adaptation measures.

2.2. Drought Assessment

Drought assessment concepts can be grouped into those which deal purely with the science of climate (e.g. the focus in this study on the Asian–Pacific Monsoon), and climate and its environment, economic, and social contexts. The links between the two are drought indices which are used to measure changes in climate and to link with its context. Drought indices (DIs) are used (i) to identify drought occurrence including the onset, duration, and end, and (ii) to measure drought severity (McKee *et al.* 1993; Alley 1984). Drought severity (as measured by DIs), in other words the severity of impacts manifesting from water deficiency, can be measured against a particular fauna/flora species, household, community, social class and the like.

2.2.1. The science of climate and drought

Rainfall in Asia is associated with wind direction, resulting from winds blowing moist air from the sea over land and rainless conditions occur when the wind is blowing from land to sea. This annual wind reversal is known as the monsoon (Ramage 1971). Based on rainfall patterns in the Asia–Pacific, there are at least three sub–regions of monsoons known as the Indian Summer Monsoon (ISM), the East Asian Summer Monsoon (EASM), and the Western North Pacific Summer Monsoon (WNPSM) (Wang & Lin 2002). The Asian land mass experiences monsoon events in different ways. The Indochina region for example is subject to complex monsoonal patterns. Wang and Lin (2002) consider this region as a buffer zone, while Qian and Zhu (2002) consider it to be a unique monsoon subsystem. Murakami and Matsumoto (1994) include Indochina in the Southeast Asian Monsoon (SEAM) but Wang and Lin (2002) include Indochina as a buffer zone of the ISM system in their researches on the ISM, Goswami *et al.* (1999) include Indochina and call it the Extended Indian Monsoon Rainfall. Misra and DiNapoli (2013) suggested the inclusion of Myanmar, Thailand, Cambodia, Laos and Vietnam in the SEAM based on the length of wet season and strong interannual variations. Ding *et al.* (2015) further explained that the Asian monsoon is not independent from

other climate systems. Some authors even argue that the Asian monsoon is a global monsoon phenomenon (Trenberth *et al.* 2000).

There are a number of factors that influence monsoon behaviour in Asia. Ding *et al.* (2015) suggest that the main influencing factors are the Tibetan Plateau, and the Pacific and Indian Oceans. The changing heat fluxes over the Tibetan Plateau have been found to influence East Asian summer rainfall (Hsu & Liu 2003). Hung *et al.* (2006) showed that the early onset of the monsoon occurs when (i) the tropical western Pacific is getting warm in April–May, (ii) the western Pacific subtropical high shifts eastward, and (iii) twin anomalous cyclones develop early. Normally, the onset of East Asian Summer Monsoon (EASM) is in early May, starting in the Bay of Bengal and reaching the South China Sea in late May (Zhang *et al.* 2004). The monsoon withdrawal starts around September (Hsu 2005). The Indian Ocean is another major influence on the Asian Monsoon. The onset of the summer monsoon over Indochina is partly influenced by the northwestward progression of a low–level southwesterly airflow over the Indian Ocean (Zhang *et al.* 2002).

Droughts and floods are associated with the climate variability discussed above. The general climate variations can be grouped into interseasonal, interannual, and interdecadal variations. These variations are associated with monsoon onset (i.e., changing onset dates of the monsoon), the total amount of rainfall in the wet season (or per year, per decade), and the cessation of rainfall. These rainfall parameters can be interrupted by many factors resulting in drought and/or flood episodes. For example Krishnamurti *et al.* (1989) argued that drought during the summer monsoon in 1987 was caused by (i) planetary scale divergent circulation over the Pacific Ocean on the eastward equator during El Niño activities, (ii) the counter monsoon flow driven by a SST (Sea Surface Temperature) anomaly over the near–equatorial southern Indian Ocean, and (iii) the pressure changes over the Tibetan Plateau. A similar investigation on monsoon failure in 1994 by Park and Schubert (1997) found that there was a seasonal zonal wind change caused by a northward shift of the jet stream over the Tibetan Plateau.

El Niño activities are associated with SST anomalies at a number of locations along the equator in the Pacific Ocean (Figure 2.1). Some authors classify the El Niño activities into a 'cold tongue El Niño' located at region Niño 3 (Figure 2.1) and a warm pool El Niño at region Niño 4 (Kug *et al.* 2009). An anomaly occurs when the SST is ± 0.5 for five consecutive 3–month running means over a region (positive in an El Niño event, and negative in a La Niña). This measurement is also known as the

Ocean Niño Index (ONI). The most commonly used region for drought monitoring is the Niño 3.4 (NOAA 2015). For example, Lyon (2004) used Niño 3.4 to measure the strength of the El Niño and the extent of drought in tropical regions. Gadgil *et al.* (2004) found that Niño 3.4 is very well correlated with Indian Summer Monsoon rainfall. It has also been used to understand drought occurrences in Thailand (Ueangsawat & Jintrawet 2013), Indonesia (Naylor *et al.* 2001) and Malaysia (Tangang & Juneng 2004), while Lyon (2004) used it to identify the spatial extent of tropical drought. There are other authors who use Niño 3 including Ashok *et al.* (2001), Niño 4 (Lagos *et al.* 2008; Kane 1999), or Niño 1+2 (Bejranonda & Koch 2010).

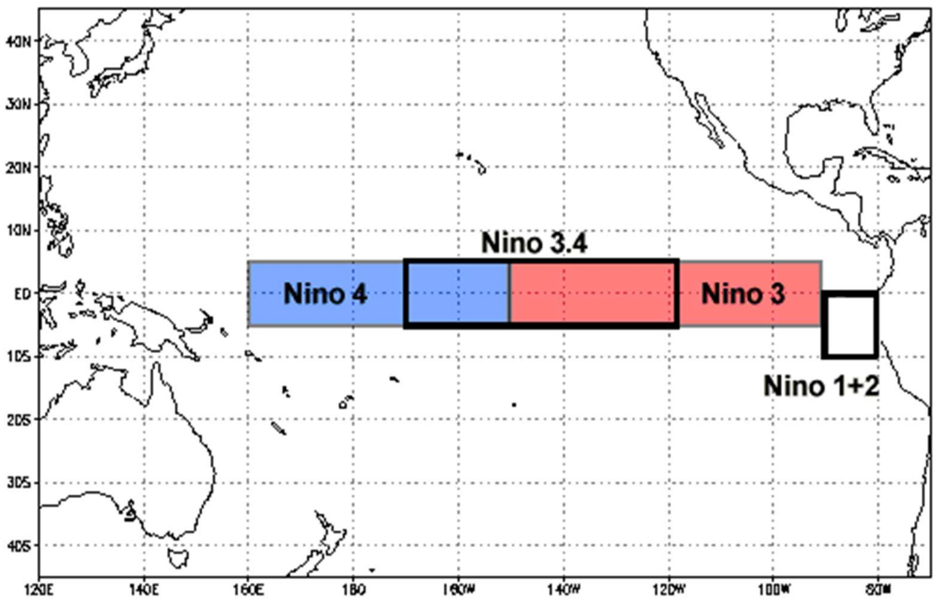


Figure 2.1: Niño Zones in the Pacific.

Source: www.ncdc.noaa.gov/teleconnections/enso/indicators/sst.php

In the last 60 years, there have been a number of events classified as El Niño (associated with drought in Asia) and La Niña (associated with flooding) based on the Oceanic Niño Index in region Niño 3.4 (Juneng & Tangang 2005). These are shown in Table 2.1.

Table 2.1: El Niño and La Niña Years.

El Niño			La Niña		
Weak	Moderate	Strong	Weak	Moderate	Strong
1952-53	1951-52	1957-58	1950-51	1955-56	1973-74
1953-54	1963-64	1965-66	1954-55	1970-71	1975-76
1958-59	1968-69	1972-73	1956-57	1998-99	1988-89
1969-70	1986-87	1982-83	1964-65	2007-08	1999-00
1976-77	1991-92	1987-88	1971-72		2010-11
1977-78	1994-95	1997-98	1974-75		
2004-05	2002-03		1983-84		
2006-07	2009-10		1984-85		
			1995-96		
			2000-01		
			2005-06		
			2008-09		
			2011-12		

Source: http://ggweather.com/enso/oni.htm.

Along with ONI, there are other indices that are used to study climate. For example, the Multivariate ENSO Index (MEI) has been used to compare drought severity from 1950-1997 (Wolter & Timlin 1998). Some authors have proposed a new index – El Niño Modoki – to monitor drought (Taschetto & England 2009; Ashok *et al.* 2007; Weng *et al.* 2007). The Southern Oscillation Index (also known as the pressure differential between Tahiti and Darwin, Australia) is also used to monitor drought development globally (Bhalme & Jadhav 1984). However, drought occurrences are also small scale, local phenomena and climatologists have proposed other indices to measure drought in these situations, such as the Palmer Drought Severity Index and Standardized Precipitation Index. The latter is discussed in Section 2.2.2.

2.2.2. Indices to measure drought

Drought is a condition that is compared with normal/average precipitation and broadly defined as meteorological, agricultural, hydrological, and/or socio–economic drought (Wilhite & Glantz 1985). In identifying meteorological drought, Palmer (1965) proposed an index known as the Palmer Drought Severity Index (PDSI). PDSI has been used to study drought over small regions (Horváth 2002), countries (Makra *et al.* 2002), continents (Briffa *et al.* 1994), and at a global scale (Dai 2011). In the current literature, PDSI is considered as an agricultural drought index. This is because it is parameterised based on soil moisture, while meteorological drought is based on precipitation. The

Standardized Precipitation Index (SPI), proposed by McKee *et al.* (1993) is a meteorological drought index.

SPI is popular due to its ease of use; it requires only one parameter (precipitation) and is applicable to general climate conditions. Tsakiris and Vangelis (2004) found that SPI has universal applicability. When comparing seven different meteorological drought indices, Smakhtin (2006) and Morid *et al.* (2006) found that SPI performed better than the rest especially when referencing drought onset and exhibited spatial and temporal consistency. There is a range of studies which have used SPI at different geographical scales. Patel *et al.* (2007), for example, used it for evaluating drought in Gujarat State in India, Edossa *et al.* (2010) used it at a watershed scale, and Hao *et al.* (2014) applied it to global drought monitoring. Other meteorological drought indices are worthy of note such as percent of normal precipitation, and rainfall deciles (Sheffield & Wood 2012). Definitions of agricultural and hydrological drought are beyond this thesis, but can be found in Sheffield and Wood (2012), Nagarajan (2009) and Rossi *et al.* (2007).

SPI has been linked to Ocean Niño Indices (ONI). For example, Mo and Schemm (2008) used SPI to link with ENSO activity to identify cold and warm conditions over the Southeastern United States. Lyon (2004) linked SPI with Niño 3.4 to understand drought extent over tropical areas. The benefits of linking SPI with ONI are that ONI is based on long term time series precipitation data, which is recorded on a regular base and generally is freely available on the World Wide Web. The ONI can also provide a lead time ranging from one to three months (Su *et al.* 2005) and therefore, it can be used to monitor drought development with these lead times.

SPI has been used to conduct drought assessments, but it is not enough on its own. The outcome of a lack of precipitation, reflected through SPI, must be viewed also from social, economic, and environmental perspectives. Many authors in the natural hazard literature agree that damage and/or disasters are the outcomes of the failures of community, civil society, or technical plans/preparations (Smith 2013; Cutter *et al.* 2003; Hewitt 1997; Blaikie *et al.* 1994; Burton 1993; Kasperson *et al.* 1988; White 1974). Wilhite (2012) argued that drought is an insidious natural hazard, creating cumulative harmful impacts over broad areas. While quantifying drought severity based on SPI has some value, understanding the root causes of drought vulnerability is also necessary.

2.3. Drought Vulnerability

There are a number of perspectives on drought vulnerability. Based on the climate change literature, climate change vulnerability (in which drought is also included) is composed of exposure, sensitivities and adaptive capacity (McCarthy *et al.* 2001). The Hyogo Framework for Action posited that 'disaster risk arises when hazards interact with physical, social, economic and environmental vulnerability' (United Nations 2005, p. 1). The theories behind the vulnerability concept, however, can be a composition of many other determinants including political economy (Blaikie *et al.* 1994; Sen 1981) and social structures (Scoones 1998). The common determinants shared among the theories are external factors such as floods and droughts and internal factors, including the individual or community capacities to handle the external threats. This section aims to comprehend the theories developed to address drought. It reviews theories of social and political economy and research related to climate change *impact assessment*, climate *risk assessment*, and disaster *risk reduction*. In this section, particular attention is given to developing countries generally and Cambodia specifically.

From the social and political economy perspectives, climate hazards are assessed through a number of models. There are at least four dominant conceptual frameworks employed to understand climate hazards such as drought, and the interrelated factors that contribute to natural disasters, as developed by Sen (1981), Blaikie *et al.* (1994), Cambers *et al.* (1992), and Ellis (2000).

Sen (1981) developed the entitlement and endowment approach (EE approach) to understand the causes of poverty and famine, arguing that a person living in a society running on private ownership and trading systems is socially legitimated to the endowment of the person (legally owned resources including own labour or land) and to exchange entitlement mapping (the use of endowment of the person to get goods and services). Sen argued that famine implies starvation and starvation implies poverty. A person suffers starvation not only because of the lack of food but also deprivation of exchange entitlement. In Sen's description, the person will face starvation, in other words food insecurity, depending on:

1. whether they can find employment, and if so for how long and at what wage rate;
2. what they can earn by selling their non–labour assets, and how much it costs them to buy whatever they may wish to buy;

3. what they can produce with their own labour power and resources (or resource services) and what they can buy and manage;
4. the cost of purchasing resources (or resource services) and the value of the products they can sell; and
5. the social security benefits they are entitled to and the taxes, etc., they must pay.

When reflecting on the entitlement concept in *risk management*, the concept lends itself to the Pressure and Release Model (*PAR* model). While starvation is the condition that a person or community experiences in food supply decline and deprivation of entitlement, PAR regards this condition as the progress of vulnerability. To experience a disaster, the PAR model developed by Blaikie *et al.* (1994) argued that people and/or communities are in between natural hazards, such as drought, and the progress of vulnerability, known as 'Pressure'. The pressures comprise three dimensions namely the root causes, dynamic pressures and unsafe conditions. The three dimensions can be viewed as having cascade effects on a community, household, and/or a person.

The 'root causes' in the PAR concept are the underlying factors that drive society to function, for example economic structure (such as private ownership, the market economy or the centrally–planned economy), culture and/or ideology of the society. The second dimension is 'dynamic pressure'. It occurs in the place where the community is living and includes, for example, the lack of local institutions or rapid population growth. Given that the first order is favourable for paving the way for people to escape from disaster, the second plays a critical role in the ability to lift people from disaster if a hazard which affects the community such as drought or flood occurs. The third order of the PAR concept is the level of 'unsafe conditions' in which people are living. They may be living in a fragile environment such as only having access to poor soils, a polluted environment and/or they are economically limited (e.g. low income). In summary, it is the condition that prohibits people from expanding their capacity to cope with natural hazards.

The PAR model required that the progression of vulnerability that creates pressure must be investigated. There should be a smooth social relationship and flows of surplus produced by households and/or communities to avoid risk; this is termed the release component of the PAR model. Sen (1981) and Blaikie *et al.* (1994) both examined vulnerability as a social problem. Sen called it starvation, while Blaikie *et al.* called it *risk*. While Sen sought solutions predominantly from economic systems, Blaikie *et al.* explored the problem in relation to social, political and economic

systems. They also argued that the physical conditions in which the people live were the part of the risk. Starvation and risk are triggered by poverty; therefore, addressing poverty means addressing starvation and risk.

Poverty is at the front line of development. Theory in addressing poverty is found in the sustainable livelihoods approach (SL). The SL approach was developed to ensure that the poor are at the centre of development, especially in rural development (Chambers & Conway 1992; Chambers 1988). In the SL approach, the poor are conceptually understood by measuring their livelihood assets (namely human, natural, financial, physical, and social capital), the vulnerability context (such as drought) and the influencing factors or transforming structures and processes (such as policies). In the vulnerability context, livelihood assets influence the status quo of a person or a community, and from this status quo they, the community, will seek their/its livelihood strategies which result in other outcomes. Temporally, these outcomes will feedback to a new status quo. Improvements in the status quo came about by diversifying livelihood strategies. This is a central concept of the SL approach.

The livelihood strategies in the SL approach are similar to entitlement exchange in the entitlement approach. The diversification of livelihood strategies or more effective entitlement exchange is the key to poverty or starvation reduction. In the PAR model, reducing the vulnerability, which is similar to improving the status quo, is the key to avoid disasters. The three approaches are implied in Ellis (2000). Ellis attributed households as the economic entity which interacts with risks according to agrarian changes. He argued that the window of opportunity to poverty reduction in rural areas is to enrich rural diversification. He posited six determinants of the livelihood diversification: seasonality, risk strategies, labour markets, credit market failure, asset strategies and coping behaviour and adaption. Ellis was convinced Sen, that markets play a critical role in promoting diversification. They also agreed that policies that inhibit mobility, provide inadequate information, and set barriers that limit household diversification are disadvantageous. The vulnerability concept is evolving from being poor to being susceptible to disaster, especially in the context of climate change.

There is an emerging school of thought on vulnerability, especially in climate change studies. Changing climate**,** induced by increased greenhouse gas emissions, includes increasing temperature, early or late onset of rainfall, increase in frequency and intensity of drought, precipitation, storms,

and sea level rise (Solomon *et al.* 2007). Conceptually, the term vulnerability has become a subject for debate among scholars by employing different terms to mean similar things within different disciplines (Füssel 2007; Janssen *et al.* 2006). Adger (2006) reviewed the term extensively and concluded that given the conceptual divergence, the term vulnerability must reach its maturity in respective disciplines to warrant benefits and sustainability for all. For climate change research, the prominently cited definition of vulnerability is from IPCC 2001:

> the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity' (McCarthy *et al.* 2001, p. 995).

The concept of vulnerability presented here can be apportioned into three dimensions including exposure, sensitivity and adaptive capacity. Each dimension is conceptually different. Exposure is defined as in IPCC glossary 'the nature and degree to which a system is exposed to significant climatic variations' (IPCC n.d). The definition holds two elements 'climate' and 'a system'. It is the 'significant variation' to which a system is exposed (called exposure) that causes threats.

For the exposure dimension, there is a consensus on physical factors. Exposure can also be equivalent to natural hazards such as drought as used in the Entitlement Approach, PAR model, and SL Approach. Exposure can be understood temporally in relation to natural hazards by its intensity and/or frequency. For example, the drought severity index can assess drought intensity between cropping seasons. The rainfall intensity can be expressed in terms of the speed of onset or cessation of and/or rainfall variation. In terms of drought, late onset and early cessation of rainfall will impact on the length of the cropping season, harvested area and yield. The variation in the amount of rainfall during crop growth will also impact crop yield and individual events can damage rice plants. An increase in exposure of a crop to drought can be expressed in terms of drought frequency, drought intensity or both.

Sensitivity is denoted as the degree to which a system is affected, either adversely or beneficially, by climate–related stimuli (McCarthy *et al.* 2001). In terms of the dimensions of sensitivity, it is the relationship between the change in physical factor(s) and the change in the system(s). For example, there may be a linear relationship between changes in rainfall parameters (climate variability) and crop yield. Paddy rice is sensitive to climate change effects. Although, climate variability in a certain

region is the same, the resulting crop yield will vary from farm to farm; the concept of sensitivity is interrelated with adaptive capacity. Then, it can be said that sensitivity is the inverse of adaptive capacity: the higher the adaptive capacity, the lower the sensitivity.

Adaptive capacity refers to 'the ability of a system to adjust to climate change (including climate variability and extreme) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (McCarthy *et al.* 2001, p. 21). While there is a shift of focus from mitigation (being viewed as opposed to adaptation) (Paavola & Adger 2006) to adaptation. The concept of adaptation analysed by Smit *et al.* (2000) is based on three enquiries namely adaptation to what, who or what adapt, how adaptation occurs and how good is the adaptation. ADB (2009) and Turner *et al.* (2003) have suggested a concept of climate resilience by blending (where possible) adaptation and mitigation to reduce the confusion of the many options to assess adaptive capacity.

The interpretation of vulnerability varies. According to Kelly and Adger (2000), it may be based on the original definition of 'vulnerability' which is derived from a 'wounded soldier' who already injured, is vulnerable to any further attacks. In development studies, socio-economic well–being and institutional condition (so called social vulnerability) are compared with the injury which makes a community vulnerable to a natural hazard. Actions to address social vulnerability may reduce risk from a hazard like climate change. Kelly and Adger limited their discussion to current vulnerability (O'Brien *et al.* 2004). O'Brien and her colleagues suggested that vulnerability assessment should be divided into time frames between the 'end point' and 'starting point'. While the starting point can be compared with the social vulnerability concept posited by Kelly and Adger, 'end point' vulnerability analysis is proposed to overcome different vulnerability contexts. O'Brien *et al.* demonstrated this 'context based vulnerability' by comparing vulnerability to climate change in Mozambique and Norway. Similar suggestions were made by Füssel (2007) in a comparison of Tibet and Florida. The highlight of O'Brien *et al.*'s thesis is that viewing vulnerability at a 'starting point' enables policy makers to address in–system sensitivities and viewing it from an 'end point' allows policy makers to reduce, say, greenhouse gases (mitigation) or reduce exposure (adaptation). Whatever the form of vulnerability assessment, they must be driven by climate change policy, goals and targets in the climate change arena (Hinkel 2011). In short, setting a universal vulnerability framework is difficult, though this is the motivation to develop a synergistic vulnerability concept (Figure 2.2).

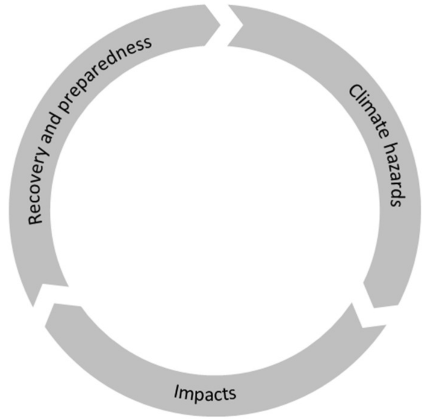


Figure 2.2: Climate Risk/Vulnerability Assessment Framework.
Sources: Modified from UNISDR (2007), Turner *et al.* (2003), and Kates (1985).

From the above discussion, it could be summarised and drawn a shorter framework for climate risk assessment as follows. The IPCC is focusing on future climate and what the intensity and frequency of hazards will be when global average temperatures are higher. Social scientists are interested in the current socio–economic status of people who could absorb the impacts, while engineers are interested in building infrastructure to withstand impacts. From a policy perspective, a full picture of climate hazards is required. For example, how do hazards occur? What are the impacts, and how should we prepare for them. These questions form the 'hazards–impact–preparedness' loop shown in Figure 2.2. The loop is similar to Kates (1985) on 'Climate Impact Assessment', Blaikie *et al.* (1994) with the 'Seven Steps of Climate Impact Assessment', Turner *et al.* (2003) on 'A Framework for Vulnerability Analysis in Sustainable Science', and IPCC (2014) on 'Climate Change 2014: Impacts, Adaptation, Vulnerability'. The loop can be used to examine empirical research and whether the research is focused on a particular aspect or encompasses the whole loop.

In terms of social science, Figure 2.2 should be read as a loop that suggests that the Impacts we experience today are due to lack of preparedness (root causes) which have allowed climate hazards to manifest on individuals and/or society. For the climate scientist, Figure 2.2 suggests future impacts will be due to the lack of adaptation/mitigation at the present time and if no action is taken. In this research, the loop concept is used to evaluate drought adaptation and/or mitigation in agriculture in Cambodia and each component is assessed individually.

2.4. Empirical Research on Drought Assessment

Given the debate on risk and vulnerability, the practices of risk and/or vulnerability research must be practical and/or policy oriented (Hinkel 2011). Lipper *et al.* (2014) posited that evidence–based research and actions would address food and climate security. Aimed at reducing vulnerability of agriculture (based on the risk management concept), especially wheat yield, Luers *et al.* (2003), evaluate the potential impacts when changing stressors – temperature change and wheat price – and changing adaptive capacity. They found that vulnerability is mainly driven by production costs, which may increase due to water scarcity. The policy implication is implied changes in management practices in wheat production. Luers *et al.* (2003) recommended that to reduce future impacts, preparedness (management practices) must be carried out in relation to water resource scarcity rather than to price fluctuations in wheat markets. Morton (2007) stressed that there are other non–climate stressors which, in turn, exacerbate the vulnerability of smallholder and subsistence agriculture.

Based on the IPCC framework, Ebi *et al.* (2011) assessed vulnerability of potato and maize farmers in Mali. Using climate change scenarios for 2030 and 2060, they found that the predicted decline in potato yield is high under current capacity and recommended that increased irrigation and adoption of heat–tolerant varieties would reduce risk. Their study used projected hazards and current adaptive capacity for preparedness (adaptation) to reduce future impact. Below *et al.* (2012) studied household level vulnerability using socio–economic data. Using the past experience of households in the face of climate events, and the current socio–economic status, they were able to prescribe policy interventions to better prepare for future climate hazards. Berkhout *et al.* (2002) employed scenario methods to explore changing climate and socio–economics and predict likely impacts.

2.4.1. Assessing economic impacts of drought

Economic impacts of drought relate to the changes in production, distribution and consumption of goods and services disturbed by drought. Computing economic costs of drought is arduous and Logar and van den Bergh (2012) confirm that studies on the costs of drought are scarce. The first task before estimating the costs of drought is to define 'what is drought'. As there are hundreds of definitions (Wilhite & Buchanan–Smith 2005) which have been developed to suit various disciplines (Wilhite & Glantz 1985), selecting and/or redefining the drought definition is the first step. Next, the scale of drought impacts can be ambiguous. For example, while drought reduces yields, the crop prices may increase. Thus, some will benefit from drought while others experience losses. The

impacts may, moreover, be measured in two–dimensions: form of damage (direct and indirect), and measurement (market and non–market) (Logar & van den Bergh 2012; Wilhite *et al.* 2007). Direct impacts may be crop loss which will result in indirect impacts such as reduced income and/or migration as a coping mechanism.

There are several economic approaches to the study of drought impacts (Logar & van den Bergh 2012) ranging from complicated data intensive models such as computable general equilibrium (CGE), to simple approaches such as Input–Output Analysis. Some models account for drought variables to see the effects of the predictor variables while others do not. For example, Horridge *et al.* (2005) employed TERM (The Enormous Regional Model) to calculate the impact of drought in Australia from 2002 to 2003 (the most widespread for the last 20 years). The model (assuming that changes in rainfall in 2002–2003 affected agricultural production) estimated changing input–output, especially in the agricultural sector and employment and found that the 2002–2003 drought reduced Australian agriculture output, on average, by about 30 percent and employment by 0.8 percent.

Based on a drought that occurred in 2002, Diersen and Taylor (2003) estimated direct and indirect impacts in South Dakota using observations of changes in agricultural production between drought and normal years. These included pasture loss, increased feed costs, culling loss, grain/oilseed loss, hay loss and other effects. The indirect effects of drought were measured in the form of multiplier facets derived from IMPLAN Pro (a social accounting and impact analysis software package). The study found that the overall impact of the 2002 drought to the farm sector in South Dakota ranged from USD 650 to 800 million.

A comprehensive study on drought costs was conducted by Pandey *et al.* (2007) in India, China and Thailand. It compared production in normal years with that in drought years by taking rainfall as the one of the indicators that affects all aspects including production loss, poverty and environment. This study found that the probability of drought ranges between 0.1 and 0.4 and production losses are 5.4 million tonnes in India, and 1 million tonnes in Thailand and China. The social implications of drought loss include unemployment, migration, and engaging in agricultural wage labour.

There is no universal formula to measure the economic impacts of drought. Within a specific objective, and sector, economic costs of drought should be compared 'with' and 'without' drought mitigation mechanisms during 'drought' and 'non–drought' events or years (Mechler 2005). Then,

with the identification of drought intensity and probability based on meteorological drought, one can estimate expected losses. These are based on the recurrence intervals (probabilities) of different intensity droughts and the associated damage.

2.4.2. Assessing environmental impacts of drought

Meteorological and/or hydrological drought contributes to environmental degradation. The impacts can be viewed as short term and long term. The former relate to lack of replenishment of soil moisture, river flows, and water levels in wetlands (the latter would be related to groundwater fed systems), water quality, and breeding success of fish, other vertebrates, and invertebrates. The water quality, moreover, is critical to people as well as to fauna and flora. Groundwater depletion, especially in coastal and arid areas, leads to salinity. For example, Adamson and Bird (2010) found that abnormal low flows in the mainstream of the Mekong River caused saline intrusion in the delta in Vietnam. The consequent economic losses were enormous. They also claim that the low flow leads to lower fish productivities in the inland fisheries of Cambodia, especially in the Tonle Sap Lake.

Bond *et al.* (2008) conducted a review of the impacts of drought on freshwater ecosystems in Australia and found that running water ecosystems are very sensitive to drought in the long term. They also found that meteorological and hydrological drought are not the only triggers, but also that land use change and increased water abstraction from the river systems can exacerbate drought severity.

2.4.3. Assessing the social impacts of drought

Economic and environmental impacts of drought consequentially lead to social impacts. Social impact of drought, then, refers to the disruption to people's lives caused by any type of drought. Based on the severe 'one in 100 years' drought in 2002–03, Alston and Kent (2004) studied the social impacts on farm families in Australia. They investigated the linkages between the economic implications (debt), losses of crop and livestock, access to education, employment, health, and social interactions, amongst other social indicators. Using focus group discussions, household surveys and field observations, they concluded that drought has had significant impact on society, especially loss of income and increased poverty. Isolated communities experienced interruptions in education and other services, and greater loss of employment. Health was major problem during drought years. Dean and Stain (2010) studied the emotional impact of drought on children in rural Australia, when

their water storages are empty and they have to cart water all the time. They found that children are emotionally saddened by the degrading environment around them due to drought.

Historical studies show that drought has contributed to the collapse of societies with strong agrarian bases. For example, Huang *et al.* (2002) used soil–sedimentary data to identify abruptly increased climatic aridity and concluded that the aridity contributed to crop failure, massive migration and the dislocation of political capital and cities of the predynastic Zhou in China. Buckley *et al.* (2010) linked the demise of the ancient Angkor City in Cambodia with a climatic downturn. They reconstructed early monsoons by correlating PDSI with tree ring–width in *Fokienia hdginsii;* then related PDSI to sea surface temperature (SST), which is influenced by the El Niño–Southern Oscillation (ENSO). Having identified severe droughts during the period of the demise of Angkor City, the authors claim that El Niño events led to droughts which disrupted water supply for agriculture and the demise of the city.

2.5. Drought Response Framework

There are perhaps three major models for response to environmental risks including those proposed by the United Nations secretariat of the International Strategy for Disaster Reduction (UNISDR), by the Organisation for Economic Co–operation and Development (OECD), and by the United Nations Framework Convention on Climate Change (UNFCCC).

The UNISDR proposed a broad framework to build drought resilient societies. The framework is the combination of '(i) policy and governance, (ii) drought risk identification and early warning, (iii) knowledge management and education, (iv) awareness and education, and (v) mitigation and preparedness' (UNISDR 2009, p. 9). Within the framework, drought identification (DI) and early warning (ES) is the central part of the resilience of society to drought, and without it any society is vulnerable to drought (UNISDR 2009). The major role of DI&ES is that it will trigger actions to combat drought hazards. A society with DI&ES systems responds to drought proactively, while one without systems will be reactive, managing the drought in crisis mode rather than managing the risk.

Given the framework proposed by UNISDR, drought is not well addressed by many countries around the world. Wilhite *et al.* (2014) argue that most drought management is 'crisis management' while it should be 'risk management'. Crisis management (or actions to recover from drought impacts) is the way in which stakeholders assess impacts, initiate responses, help affected communities to

recover, and provide reconstruction if needed. If drought response is reactive, it will not be efficient. Actions need to be more proactive to protect communities from disasters, e.g., having drought mitigation planning, monitoring and protection mechanisms. To ensure proactive drought management, Wilhite *et al.* (2014) propose a ten–step approach ranging from forming drought task forces to evaluate drought impacts to revising drought mitigation plans.

Drought is a risk faced by households and national economies, affecting global trade and food security. As agricultural products are major export commodities, Australia, the United States, and many OECD countries have been trying to reduce risks to agriculture. Amongst ideas proposed is a holistic framework for risk management in agriculture (OECD 2011). The framework proposes three layers of risk (normal risks: small damage but frequent; marketable risks: middle range; and catastrophic risks: rare with high damage and systemic). To manage these risks, the framework proposes the following strategies: on farm strategies (including diversification and saving); market tools (forward contract or private insurance); and ex ante/ex post policies (disaster assistance including payment and/or public insurance). For example, normal risks include variations in production or price which must be managed by farmers while catastrophic risks such as severe drought require market management or government involvement such as insurance. There are no clear boundaries between these layers of risk.

The current literature on climate change issues especially Loss and Damage[2] emphasises three approaches in response to climatic hazards for risk management including risk reduction, risk retention, and risk transfer. The coordination of these approaches must include involvement from institutions, governance and other stakeholders (Habiba & Shaw 2013; UNFCCC 2012). Risk reduction is mainly associated with actions to reduce risk prior to the event, which is partly related to adaptation in climate change literature and disaster risk reduction in hazard risk literature. Risk retention, as discussed in the UNFCCC document, is mainly associated with financial security after experiencing disaster including loans or social funds. Finally, risk transfer literally means to buy insurance to cover loss and damage caused by natural disasters.

The three models appear to be different and each has its own merits, but they share many commonalities. For example, identifying risk and vulnerable subjects are compulsory tasks for all

[2] The third pillar for combating climate change, with mitigation and adaptation being the first and second respectively.

the models. The solutions could be to adapt to the hazards, to mitigate the hazards, and/or reduce people's or environmental vulnerability. The UNISDR model shows the process as a flow from one agent to another while the OECD model shows what actions need to be taken by stakeholders based on layers of risk. The UNFCCC model seems to combine the two approaches.

Empirical research on risk management shows that many farmers in Africa believe that God punishes them by giving them less rain, and they pray to God for rain (Slegers 2008). Nonetheless, some farmers also reduce their drought vulnerability through land management practices such as cultivating immediately after the first rains and by controlling weeds. Changing crop varieties including short duration maturing varieties and/or drought tolerant varieties are also common practices among farmers (Ouk *et al.* 2006). Cultivation practices such as Systematic Rice Intensification is also recommended and practiced in drought prone areas (Yang 2012). Researchers also found that deeper transplanting of rice from 26cm to 37cm increases yields and avoids drought as plants utilise deeper soil moisture in the rooting zone (Bell & Seng 2003). From a household perspective, Pandey *et al.* (2007) classified drought coping strategies that households employ to either to reduce risk or reduce impacts into ex ante and ex post. In their comparative study of three countries (China, India, and Thailand), they found that farmers sought additional employment in the nonfarm sector to reduce drought impacts on their households. Some farmers sold their productive assets (such as bullocks), or used savings, and/or borrowed capital.

In developed countries, drought responses are shared by households and the government. For example, Heathcote (1974) found that households increased mechanisation of farm operations and implemented soil conservation measures which considerably reduced drought impacts. Mechanisation can speed up cultivation while the soil has an adequate moisture level and assist plants to root quickly. It has been estimated that the annual cost of reducing drought impacts is about USD 19 per person in Australia; a cost was shared by households and the government (Kates 2014). Comparing drought measures in developed countries, Wilhite (1986) found that Australia was better prepared for drought (having more proactive measures) than the United States. Given good policies to address drought in Australia, Nelson *et al.* (2008) suggested that the government must have adaptive governance in which local communities and multiple stakeholders can be involved in addressing drought impacts so that they can achieve multiple and shared goals.

In the context of climate change, climate variability is intensified by global warming and the literature is replete with mitigation options to reduce impacts such as reducing greenhouse gas (GHG) emissions. For instance, Canadell and Raupach (2008) found that forests in tropical regions can absorb significant amounts of global CO_2 which can reduce the impact of global warming. Moreover, scientists have argued that clearing forests in Asian monsoon regions has altered the rainfall pattern (the onset and cessation) and amount within the region (Dallmeyer & Claussen 2011). Sen *et al.* (2004) found that deforestation within the Indochina region has significantly contributed to changing the regional climate. Reddy (2015) prescribed a number of measures for reducing GHG emissions from the agricultural sector ranging from improving crop and grazing management to using environmental–friendly (lower GHG emission) technologies in farming. In addition to the earlier discussion (Section 2.3) on climate change adaptation frameworks as a means to cope with natural hazards, additional details can be found in Pelling (2010), Smit and Wandel (2006), Gallopin (2006), and Brooks (2003). It can be concluded that efforts to reduce GHG emissions are responding to decrease in drought frequency and intensity.

2.6. Drought Monitoring and Early Warning

As discussed in Section 2.5, drought monitoring and early warning is central to drought preparedness. Gillette (1950) (cited in Wilhite & Buchanan–Smith (2005)) termed drought as a creeping phenomenon. But some authors have introduced a number of methods to monitor drought based on weather–based variables such as the Standardized Precipitation Index (SPI) which has been used to monitor drought around the world. Moreover, Morid *et al.* (2007) introduced the Effective Drought Index (EDI) as a drought early warning tool as it performed better than SPI in terms of the lead time, especially for Iran. Other methods have been used to monitor drought such as calculating the Normalised Difference Vegetation Index (NDVI) from remotely sensed data as a proxy of soil moisture deficiency. More methods and tools have been reviewed by Wilhite (2005), Boken *et al.* (2005), and Rossi *et al.* (2007).

NDVI, as tool for drought monitoring, is the mathematical manipulation of red and near infrared reflectance data acquired by space–borne or airborne remotely sensed data. It was rooted from understanding of vegetation condition by using Earth Resource Technology Satellite 1 (ERTS-1) carried with MultiSpectral Scanner (MSS), also known as remotely sensed data (Rouse Jr *et al.* 1974). The mathematical manipulation of these data, also known as NDVI, to derive vegetation condition

was developed by Goward *et al.* (1991). Based on Kogan (1995), NDVI values of bare soil, cloud and water are very low compared to healthy and dense vegetation. With an understanding of vegetation conditions and the current development of remotely sensed data, researchers have been able to understand drought conditions (e.g., Son *et al.* 2012; Gu *et al.* 2007; Kogan 1995) and monitor drought in real time (Rhee *et al.* 2010; Thenkabail & Gamage 2004; Peters *et al.* 2002). Other high temporal resolution sensors, for example the Moderate Resolution Imaging Spectroradiometer (MODIS), are also widely used for drought monitoring.

While drought monitoring and early warning of drought occurrence are now well established, local traditional knowledge on drought is also important. Roncoli *et al.* (2002) found that farmers from West Africa use flowering and fruiting production indicators for local trees to forecast drought. In Zimbabwe, farmers have used observations of wind direction, animals' friskiness and/or bird migrations (Patt & Gwata 2002). However, there is increasing literature whom cautions against over reliance on that local knowledge to understand drought (Eakin 1999). Hansen (2002) argues that scientific forecasting should be integrated with traditional knowledge when possible.

Given the three potential options (drought indices – calculated from meteorological data, vegetation indices derived from remotely sensed data – and local knowledge) as drought monitoring and/or prediction tools, perhaps, the El Niño–Southern Oscillation (ENSO) is the central component of drought monitoring and early warning. As discussed earlier, lack of precipitation is the key to a drought. Therefore, understanding the variability of precipitation should enable farmers or planners to prepare for droughts. It has been proved that the ENSO activity in the tropical Pacific impacts on environment and socio-economic conditions worldwide. Monitoring ENSO gives users a lead time – of at least a month (Su *et al.* 2005) – to prepare to manage drought risk.

2.7. Chapter Summary

Drought is the deadliest and costliest of natural disasters in developing and developed countries respectively. Drought was often believed to be the curse of deities, but it is now believed that drought is a manmade disaster linked to climate variability (United Nations 2010). Droughts happen because of a lack of understanding of how they occur, how the impacts are distributed, and how to adapt and/or mitigate from household to national level.

Unlike other natural hazards such as floods or typhoons, drought may have a slow onset and end without notice. The onset is slow because the event happens relative to the period and demand for rainfall, soil moisture, reservoir storage, and/or stream flow. There are many definitions of drought; meteorological drought refers to amount of rainfall below normal within a period, agricultural drought refers to the lack of soil moisture for plants to grow and hydrological drought means stream flow is below normal. However, all droughts are associated with impacts, therefore may be called socio–economic drought. These contexts make drought studies complicated. However, Smakhtin and Schipper (2008, p. 141) suggest simply that 'drought should only be understood as a temporary, recurrent climatic event that is originally caused by lack of rainfall'. This means that meteorological drought is the starting point of any drought study and impacts such as lack of rainfall may be translated into tangible impacts such as agricultural activities being impaired or destroyed. In the case of India for example, drought declarations are triggered by a lack of rainfall during the rainy season which is also related to the agricultural production period (Prabhakar & Shaw 2008).

Given the same intensity and frequency, impacts of drought can differ from household to household, from community to community, or from country to country. This is due to the fact that the vulnerability of households, communities, or countries differ. For example, drought in developing countries may result in loss of human and animal life while in developed countries it may result in low crop yields, loss of employment or water restrictions. Therefore, drought vulnerability and its underlining root causes are very important in understanding how droughts become disasters.

In the case of Cambodia, drought is a major barrier to households moving out of poverty and the key factor which undermines the national economy. There are calls for drought studies which can be used for drought management and monitoring. There have been a number of studies on drought in Cambodia but they have been less comprehensive than in many other countries. This thesis is expected to contribute to the literature on drought management in Cambodia.

CHAPTER 3: DROUGHT MONITORING FOR RICE PRODUCTION IN CAMBODIA

This chapter addresses research objective number one: to quantify drought severity in Kampong Speu. The chapter has been published as the following reference and been reformatted to thesis standard including styles, tables, figures, and headings. The content remains exactly the same as the journal article. The paper was peer reviewed. The journal is open source and copyright permission is not required.

Chhinh, N & Millington, A.C 2015, 'Drought monitoring for rice production in Cambodia', *Climate,* vol. 3, no. 4, pp. 792–811.

This chapter was also presented in an early form at the *Asia–Pacific Climate Change Adaptation Forum 2014, 1–3 October 2014, PWTC Kuala Lumpur, Malaysia.*

The second author contributed to revising the manuscript. The writing and analysis was conducted by Chhinh Nyda.

Abstract: Rice production underpins the national economy and most rural livelihoods in Cambodia, but it is negatively impacted by repeated droughts. The research reported on in this paper focuses on relationships between drought occurrences in Cambodia's most drought–prone province (Kampong Speu) and (i) damage to the annual rice harvest between 1994 and 2011, and (ii) the Niño 3.4 index. Droughts were identified using the Standardized Precipitation Index (SPI). In seven of the years between 1994 and 2006 droughts damaged >1,000 ha of rice in the Kampong Speu province. Furthermore, in 11 years >200 ha of rice were damaged. A critical success index of 0.66 obtained for an analysis of SPI–defined drought and area rice damage in the province indicating a strong statistical relationship. A statistically significant correlation ($r = -0.455$) was achieved between Niño 3.4 and 12–month SPI values lagged by three months, this indicates the importance of ENSO linkages in explaining drought in this region. Late season droughts lead to greater rice damage than early– and mid–season droughts.

Keywords: drought; rice; Standardized Precipitation Index, ENSO, Niño 3.4, Kampong Speu, Cambodia

3.1. Introduction

Cambodia produced 9.29 million tonnes of rice in 2012. This generated a rice surplus of 4.73 million tonnes (Ouk 2013). Annual surpluses of this magnitude should enable the country to achieve its stated aim of exporting 3 million tonnes per year by 2015 (Royal Government of Cambodia 2010b). Rice contributes 28 percent of the GDP generated by the agriculture, fisheries and forestry sector in Cambodia (International Monetary Fund 2009), but production relies on rural households working small farms (national average farm size = 1.4 ha per household) using traditional practices (Yu & Fan 2011). Over 80 percent of Cambodia's population live in such rural communities, and rely on rice as their major income source as well as their staple food. Put simply, rice underpins the national economy and the majority of livelihoods.

Yet, rice production in Cambodia is significantly impacted by droughts and floods related to inter–seasonal and inter–decadal fluctuations in the South East Asian Monsoon (SEAM)—a subsystem of the East Asian Monsoon. Droughts have been identified by the government as one of the two most important natural hazards in the country (Royal Government of Cambodia 2010a; McAndrew 1998). Their impact on rice production and drought alleviation measures have been reviewed by Chhinh (2014). The Ministry of Environment (MoE) estimated that between 1996 and 2000 drought–related rice losses were approximately 20 percent of potential national production (Ministry of Environment 2001). Since then, a severe drought in 2004 affected 300,000 ha of paddy rice leading to an 82 percent loss of the potential harvest (Ministry of Agriculture, Forestry, and Fisheries 2010). In

response to another severe drought in 2009, the government issued a USD 12 million rescue package (Chun 2009).

The occurrence of droughts and floods in Cambodia is related to the dominant climate system in Southeast Asia, the Asian–Australian Monsoon (AAM) (Ding *et al.* 2015; Yihui 2007). The East Asian Monsoon (EAM) is one of a number of subsystems within the AAM (Ding *et al.* 2015; Webster *et al.* 1998). Linkages between the EAM and socio–economic development have been highlighted by other researchers (Davolio *et al.* 2015; Yihui 2007); with particular attention being paid to droughts and heat waves (Park & Schubert 1997), and flooding (Huang *et al.* (1998) as cited in Huang *et al.* (2007)). According to Huang *et al.* (2007), the EAM led to production losses exceeding USD 24 billion annually in China (three to six percent of the country's GDP) in the early 1990s fluctuations in the EAM). Strong correlations have also been found between the EAM and droughts and floods in the Yangtze and Yellow River basins (Huang *et al.* 2007). Strong correlations have been found between the EAM and droughts and floods in the Yangtze and Yellow River basins (Tong *et al.* 2006) and along the Yangtze and Huaihe Rivers (Huang & Yan 1999; Bomin & Shuqing 1994).

The aims of this research are to explore the (i) relationship between the occurrence of droughts based on the application of a drought index—the Standardized Precipitation Index (SPI)—and the areal extent of rice damage in the most drought–prone province of Cambodia (Kampong Speu); and (ii) relationships between SPI values and indicator values for ENSO.

3.2. South East Asian Monsoon

There are contrasting views on the monsoon geography of Southeast Asia. The Asian Summer Monsoon (ASM), of which the SEAM is a sub–system, has been described as the climate system which brings rain–bearing winds that originate in the Bay of Bengal to the Indochina Peninsula and the South China Sea (SCS) (Zhang *et al.* 2002). Wang and Lin (2002) argue that while the Indian subcontinent is influenced by the Indian Summer Monsoon (ISM), Indochina is influenced by three subsystems—the ISM, East Asian Summer Monsoon (EASM), and Western North Pacific Summer Monsoon (WNPSM). Goswami *et al.* (1999) include Indochina in the zone of influence of the ISM—terming it the Extended Indian Monsoon Rainfall region. Given these geographical contradictions, it is unsurprising that the Indochina region has been the focus of many regional climate studies (Misra & DiNapoli 2013; Zhang *et al.* 2002; Chen & Yoon 2000; Kane 1999). In contrast, Qian and Zhu (2002) consider the SEAM to

be a unique monsoon subsystem in which rainfall originates both to the east and west of Southeast Asia.

Chen and Yoon (2000) have proposed two key mechanisms that affect the summer monsoon in Indochina; (i) the combined SCS and Western Pacific regional climate driver, and (ii) the global divergent water vapor flux. They also argue that sea surface temperatures (SST) in the western tropical Pacific are a good climate predictor for Indochina. Zhang *et al.* (2002) argue that (i) tropical convection triggers the onset of the monsoon, and (ii) interseasonal variability is associated with the timing of monsoon's onset which originates in the western Pacific and the SCS and propagates toward Indochina. Both Zhang *et al.* (2002) and Chen and Yoon (2000) agree that the SST anomalies influence the onset of the monsoon. In contrast to this Pacific Ocean focus, Misra and DiNapoli (2013) concluded that early onset of the SEAM is associated with moisture sources in the Andaman Sea, the Gulf of Martaban and the Gulf of Thailand, while late onset of the monsoon is associated with water fluxes from the Bay of Bengal and the Arabian Sea. Ichiyanagi *et al.* (2005) argue that during the withdrawal of the monsoon in Indochina, the moisture source changes from the Indian Ocean to Pacific Ocean.

Nigam (1994) concluded that circulation anomalies due to changes in the zonally–averaged state of the El Niño Southern Oscillation (ENSO) modulate low–level moisture fluxes over southeast Cambodia, Laos and Vietnam. ENSO and SST anomalies are linked. SST is measured at a number of locations along the Equator in the Pacific Ocean, from Niño 1 in the east to Niño 4 in the west (NOAA 2015). Anomalies occurs when the SST is $> +0.5$ or < -0.5 for five consecutive 3–month running means over one of the regions of the Equatorial Pacific (positive values create the El Niño effect, and negative values the La Niña effect). This measurement is known as the Ocean Niño Index (ONI). The most commonly used region for calculating ONI for drought monitoring is Niño 3.4 (Kug *et al.* 2009). Lyon (2004) used Niño 3.4 to measure the strength of El Niño and the spatial extent of droughts in tropical regions. Gadgil *et al.* (2004) found that Niño 3.4 is well correlated with Indian Summer Monsoon rainfall. It has also been used in Thailand (Ueangsawat & Jintrawet 2013), Indonesia (Naylor *et al.* 2001), and Malaysia (Tangang & Juneng 2004). Indices have been calculated for other regions, for example, Niño 3 was used by Ashok *et al.* (2001), Niño 4 (Lagos *et al.* 2008; Kane 1999) and Niño 1+2 (Bejranonda & Koch 2010) as well.

The annual rainfall regime in Cambodia (based on long term climate means) comprises a five–month dry season (December–April) and a longer wet season from the onset of the SEAM, normally May to November (Figure 3.1). The wet season is slightly bimodal with a dry spell that is usually centred on August. This is called *Kuon Rodow Prang* (the literal translation from Cambodian being the "child dry season"). More than 80 percent of the precipitation normally occurs in the wet season.

Figure 3.1 shows both the mean monthly rainfall for 1983–2012 for Kampong Speu and the monthly rainfall for indicative dry (1987) and wet (2001) years, and the year most impacted by drought—2004. In the two dry years—1987 and 2004—no month had more than 200 mm of rainfall and the wet seasons were marginally shorter than in 2001. The wettest year—2001—not only had more wet season rainfall than the other two years, but some 'dry season' months also had relatively high rainfall. The *Kuon Rodow Prang* dry spell varied from a pronounced decline in rainfall in August 2004 to a much less pronounced dry spell in July 1987. In 2001 there was no *Kuon Rodow Prang* dry spell.

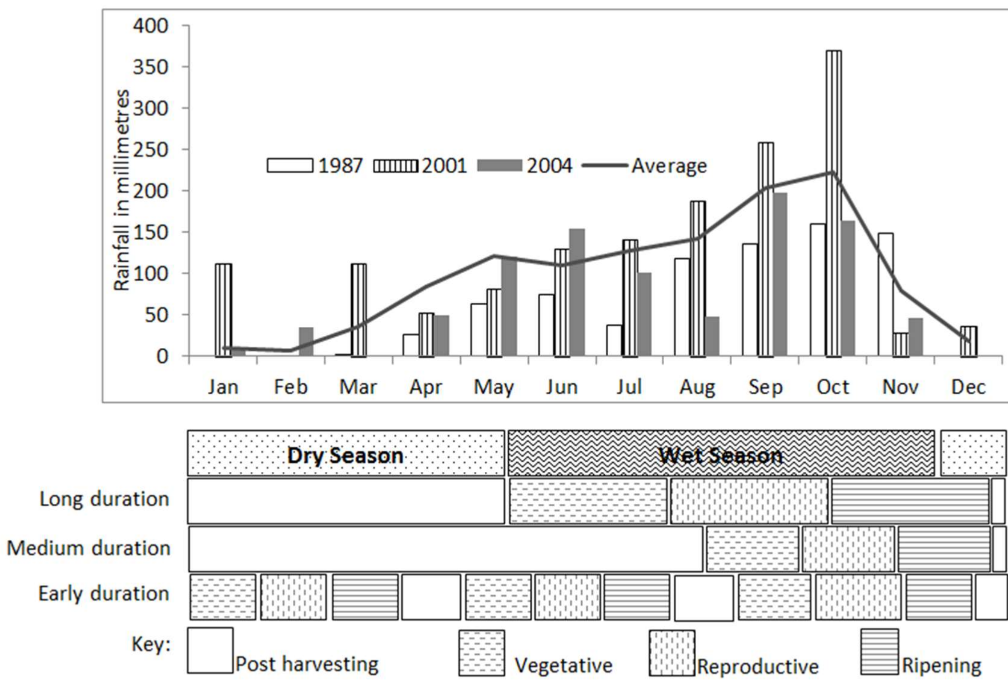


Figure 3.1: Kampong Speu climate station: mean monthly average rainfall (1983–2012) and monthly rainfall totals for three indicative years. Rice development phases for long–, medium– and early–season rice varieties are provided below the rainfall data.

Sources: Rainfall: Department of Water Resources and Meteorology, rice development data: fieldwork observation.

3.3. Monsoon Seasonality and Rice Production

Coupling precipitation records and cropping calendars (Figure 3.1) illustrates how different rice varieties are adjusted to average climatic conditions and how they may be impacted by drought. The most popular rice varieties grown in Cambodia are the traditional, long maturing rice varieties, which utilise soil moisture throughout the wet season. Seedlings of these varieties are transplanted in May and the harvest takes place in late November (Javier 1997). Medium–duration varieties have mainly been cultivated in the last two decades, whereas short–duration varieties are a more recent introduction to Cambodian farming systems. Whereas medium–duration varieties are only cultivated in the wet season, albeit for a shorter cropping period than long–maturing varieties, short season rice can be harvested approximately three months after sowing and can be grown at any time of the year. However, as Figure 3.1 shows, there are three times in the farming calendar when the majority of short–duration rice is cultivated: (a) December to March, at this time of year farmers utilise standing water and residual soil moisture, which can be supplemented by irrigation; (b) May to August, by utilising early wet season rains before harvesting in the *Kuon Rodow Prang* dry spell; and (c) September to November, when late wet season rains are exploited and the harvest coincides with that of the long– and medium–duration varieties. The proportions of the long–, medium– and short–duration rice by area planted are approximately 20, 40, and 33 percent respectively (CARDI 2001).

Susceptibility to drought can be argued from an examination of the crop calendars. Any significant change in wet season rainfall (e.g., precipitation amount, length of the season, or timing and length of the *Kuon Rodow Prang* dry spell) has the potential to affect the yields of long–maturing rice varieties. Medium–duration varieties are susceptible to the same drought–related phenomena. Short season rice is the least susceptible to drought, but nonetheless can still be affected. For example, a delayed onset of monsoon rains means that irrigation is required for the May to August crop. Helmers and Jegillos (2004) argue that drought in Cambodia occurs at three different times: in the early and middle parts of the wet season, and at the end of the year. Failure of the late wet season rains is potentially the most problematic because all three varieties of rice are harvested in November.

In 2008, the total area under paddy cultivation in Cambodia was 2.61 million ha. Irrigated paddy accounted for 31.6 percent (approximately 825,000 ha). A further 239,000 ha required supplementary wet season irrigation—mainly for May to August short–duration rice. A further

74,200 ha relied on dry season irrigation, mainly for rice grown between December and March (Royal Government of Cambodia 2010a). Even so, irrigation is limited and does not obviate the fact that drought is the most important natural hazard in Cambodia after flooding (Ministry of Environment & UNDP 2011). Consequently, monitoring drought and the damage it causes to agricultural production in Cambodia is a national priority in terms of food security and international trade. While the impacts of drought may be reduced by early interventions and improvements in infrastructure, these are unlikely to be effective unless droughts can be explained, predicted and monitored accurately.

3.4. Study Area

Kampong Speu Province (KPS) was selected for this research because of its high incidence of droughts compared with other provinces. It is located in the rain shadow of the Cardamoms and the Elephant mountain ranges and receives the least rainfall of any province in Cambodia. Mean annual precipitation ranges from 1,250 to 1,750 mm for the parts where rice is grown. Paddy fields on the small farms that dominate the province are rain–fed and have experienced drought damage that has ranged from loss of seedlings to almost the loss of the entire harvest over the last few decades.

The province covers 696,971 ha and the agricultural area in 2009 (based on the Provincial Data Book) was 167,771 ha, or about 26 percent of total land area. The province comprises 87 communes grouped into eight districts. The population in 2008 was 784,799. The smallest administrative unit is the village, which usually contain about 200 households. Farming is the primary occupation of 92 percent of households (National Institute of Statistics 2008a).

The rainfall records for the 18 climate stations in KPS are provided in Table 3.1. The majority of stations started recording data in 2000; however, there are interruptions to the records. Kampong Speu station has the longest and most complete record. Measurements were made by the Department of Agriculture (DA) from 1983 to 2003, and by the Department of Water Resources and Meteorology (DWRAM) from 2000 to the present. The interruptions in the climate records have been caused by the change in the authority responsible for data collection, flooding of the DA data archives in 2000, and the devastation caused by the 1970 to 1999 civil war.

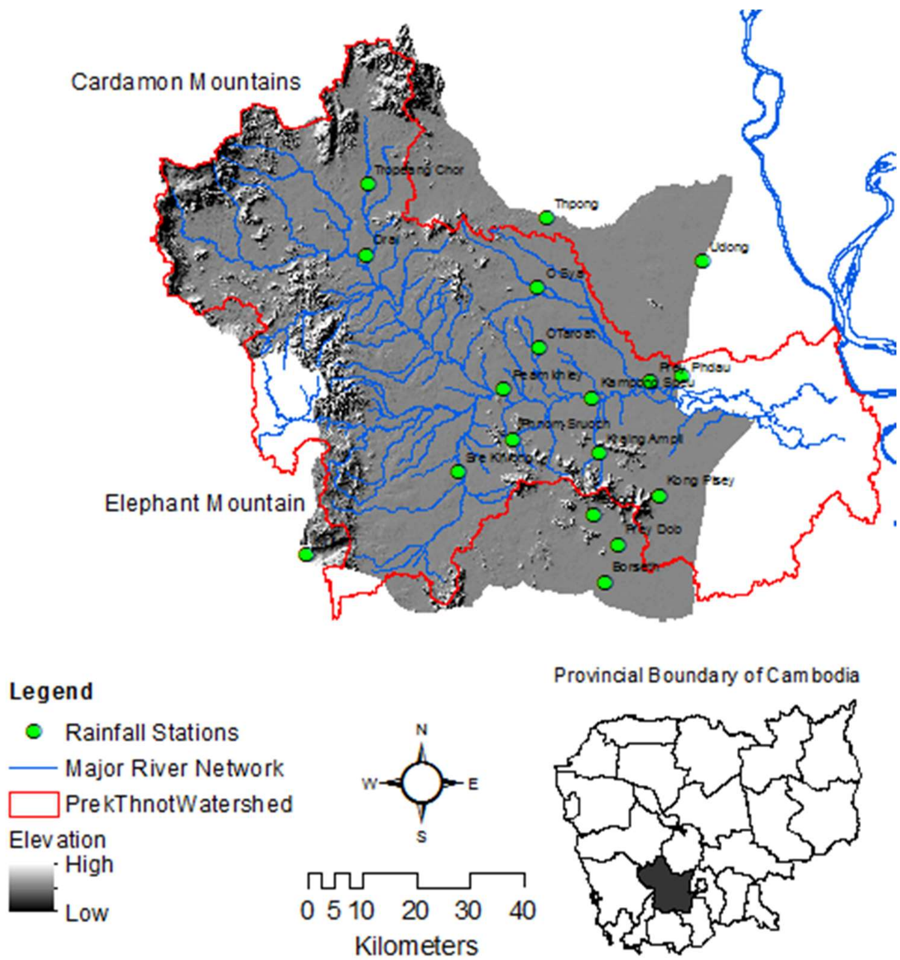


Figure 3.2: Kampong Speu Province.

Sources: Rainfall stations from fieldwork; major river network from the Mekong River Commission; delineation of the Prek Thnot Watershed from GDEM data obtained from the HEC–GeoHMS program; elevation data from the Aster GDEM; and provincial boundaries from the National Geographic Department of Cambodia).

Table 3.1: Rainfall statistics: Kampong Speu Province.

Station (see Figure 3.2)	Data range		Minimum (mm) (Year)	Maximum (mm) (Year)	Mean (mm)	Difference between mean and minimum	Difference between mean and maximum
			(a)	(b)	(c)	(a−c)/(c)	(b−c)/(c)
Kampong Speu (KPS)	1983	2012	882.7 (1987)	1,858.0 (2000)	1,315.7	−33%	41%
Thnal Teteung (THT)	1995	2009	631.7 (2004)	1,408.5 (1996)	1,059.4	−40%	33%
Phnom Sruoch (PSH)	1995	2012	654.0 (1997)	1,620.8 (2000)	1,165.3	−44%	39%
Udong (UDN)	1995	2012	901.5 (2006)	1,751.5 (2000)	1,230.3	−27%	42%
Kong Pisey (PSY)	1995	2012	862.9 (2009)	1,501.1 (1999)	1,146.1	−25%	31%
Thpong (THP)	1995	2012	704.6 (1997)	1,686.2 (1999)	1,271.2	−45%	33%
Borsedth (BST)	1996	2012	574.0 (1997)	1,708.0 (1996)	1,237.4	−54%	38%
Aoral (ORL)	1997	2012	666.5 (1997)	1,570.4 (2003)	1,169.5	−43%	34%
Prey Phdau (PPD)	1997	2012	610.3 (1997)	1,565.3 (2001)	1,164.7	−48%	34%
Peam Khley (PKL)	2001	2012	601.1 (2007)	1,424.3 (2001)	884.3	−32%	61%
OTaroat (OTR)	2001	2012	640.9 (2008)	1,336.2 (2001)	952.7	−33%	40%
Kraing Ampil (KRA)[1]	2001	2011	370.6 (2004)	1,244.4 (2001)	807.1	−70%	54%
Kirirom (KRM)	2001	2005	1158.9 (2002)	2,254.9 (2001)	1,496.7	−23%	51%
Sre Khlong (SKL)	2001	2011	924.1 (2006)	1,433.8 (2001)	1,171.5	−21%	22%
Prey Dob (PRD)	2001	2012	622.6 (2011)	1,416.3 (2009)	1,069.8	−42%	32%
Sdock (SD)	2001	2012	601.1 (2007)	1,424.3 (2001)	884.3	−32%	61%
Tropeang Chor (TRC)	2001	2011	803.1 (2007)	1,391.5 (2009)	1,066.2	−25%	31%
O Sya (OSV)	2002	2011	797.6 (2004)	1,404.9 (2003)	1,020.1	−22%	38%

[1] Rainfall data from this station is suspect. The minimum rainfall records in 2005 (122.7 mm) and 2006 (184.9 mm) are anomalously low, compared with the neighbouring stations, and were not used.

3.5. Drought Indices

Nagarajan (2009) provides detailed definitions of agricultural, hydrological, meteorological, and socio–economic drought (UNISDR 2007; Wilhite & Buchanan–Smith 2005). This research focuses on meteorological drought. Drought severity is quantified in different ways. Some authors have used meteorological data (e.g., the Palmer Drought Severity Index; Buckley *et al.* (2010), Nguyen and Shaw (2011)); others have used human perception (e.g., Ministry of Environment (2005b)); while others have measured productivity losses using indices such as the Normalised Different Vegetation Index (NDVI) from remotely sensed data (e.g., National Committee for Disaster Management (2003)). Quiring and Papakryiakou (2003) comprehensively reviewed drought indices and has argued that they play an important role in providing decision makers and other stakeholders with critical information. Many benefits accrue from deploying drought indices (Ichiyanagi *et al.* 2005; Dai *et al.* 1998; Kumar & Panu 1997; Lohani & Loganathan 1997; Karl *et al.* 1987; Wilhite *et al.* 1986;

Alley 1985; Sakamoto 1978) despite the limitations and assumptions (Wu *et al.* 2011; Ichiyanagi *et al.* 2005; Quiring & Papakryiakou 2003).

The Standardized Precipitation Index (SPI) – deveoped by McKee *et al.* (1993) – has been used in many climate zones. It is listed as a key indicator for global drought monitoring (Hao *et al.* 2014; Monacelli *et al.* 2005); and has been used for drought monitoring in the United States and India (World Meteorological Organization 2012; Pai *et al.* 2011; Heim 2002). It was used in this research because it is based solely on precipitation – and therefore is the drought index of most use in the instrument – poor situation that describes most climate stations in Cambodia. KPS is no exception, as precipitation is the only data available for most of the stations in the province. A further advantage of the SPI is that it can be calculated for different time scales. This gives it a potentially important role in understanding the impacts of dry spells on crop production. SPI has also proven suitable for monitoring floods as well as droughts in many parts of the world (Zhang *et al.* 2009; Wilhite & Buchanan–Smith 2005; Seiler *et al.* 2002).

The SPI is a probability related to a precipitation value. The standardised precipitation (SP) is the value derived from dividing the variation from the mean precipitation of a defined time period (1, 2, 3 months etc.) and the standard deviation of the data set. For example, calculation of the SPI over a three–month timescale, labelled as June 2004, would be calculated using the total rainfall for April, May and June 2004. To estimate the probability of the distribution, the gamma function is used as it fits meteorological data very well and has zero as its lower bound value (McKee *et al.* 1993; Thom 1966). As posited by Thom (1966), the probability density function of the gamma function for a time period of rainfall is:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \tag{3.1}$$

Where β is a scale parameter, α is a shape parameter, and Γ(α) is the ordinary gamma function of α. The equation requires α and β to be obtained from the following maximum likelihood solutions:

$$\hat{\alpha} = \frac{1}{4A}(1 + \sqrt{1 + \frac{4A}{3}}) \tag{3.2}$$

And

$$\hat{\beta} = \frac{\hat{x}}{\hat{\alpha}} \tag{3.3}$$

Where

$$A = ln\overline{x} - \frac{\sum lnx}{n} \tag{3.4}$$

where *n* is number of precipitation and *x* is the amount of precipitation for a particular time period.

The probability that the precipitation is less than an amount (for a particular time period) is presented in the standard form: $\mathrm{P(x)} = \mathrm{x}/\hat{\beta}$. Tables of the gamma distribution provide the cumulative probability of the specified period. The cumulative probabilities are converted into a Z–score (which becomes the SPI value). An SPI value is relative to a particular month[3] and indicates the drought severity over the specified time period. The original convention was that SPI values of 0 to < −2.0 were divided into four classes of drought ranging from mild to extreme (McKee *et al.* 1993). However, Hao *et al.* (2014) introduced five categories of drought starting at a –0.50 threshold rather that 0. These classes are defined as follows, SPI <= −0.50 to −0.79 is termed "abnormally dry", −0.80 to −1.29 is a "moderate drought", −1.30 to −1.59 is a "severe drought", −0.60 to −1.99 is an "extreme drought", and −2.0 or less is an "exceptional drought. This classification has been used in this research.

3.6. Results

SPI values were calculated for time periods of one, two, three month ending in June, August, or November and 12–months for precipitation data for Kampong Speu station (Table 3.2). The time periods developed around the three months listed above relate to the average rainfall pattern, particularly the onset of the monsoon and key aspects of monsoon variability, and paddy rice growth. In terms of the mean rainfall pattern, June is early in the wet season, August is the driest month in the wet season, and November is at the end of the wet season. June, August and November are also related to early, middle and late seasonal droughts cited in the literature (Chhinh 2014; Helmers &

[3] For Software http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx and easy to read manual http://www.wamis.org/agm/pubs/SPI/WMO_1090_EN.pdf.

Jegillos 2004). In terms of paddy rice growth, June is the paddy rice vegetative period for long maturing varieties. August usually coincides with the *Kuon Rodow Prang* dry spell and fluctuations in precipitation at that time impact on paddy reproduction. November is the maturation and grain filling period. The 12–month periods were used when applying the critical success index to the analysis of SPI–defined drought and areal assessments of drought–related rice damage.

Table 3.2: Time periods for which SPI values were calculated and the base month labels.

	1-Month SPI	2-Month SPI	3-Month SPI	12-Month SPI
Base month = June	June	May June	April May June	12 consecutive months up to June
Base month = August	August	July August	June July August	12 consecutive months up to August
Base month = November	November	October November	September October November	12 consecutive months up to November

One–month timescale: Figure 3.3 shows one–month SPI values from 1983 to 2012. Meteorological droughts of moderate severity (SPI = −0.80 to −1.29) occurred in June 1989, 1990, and 2006. There was a severe drought (SPI = −1.30 to −1.59) in 1992, and there were extreme droughts (SPI = −1.60 to −1.99) in 1997 and 2012. June 1991 was very wet (SPI = 2.24) and it was moderately wet in 1984, 1985, 1988, 2004, 2007 and 2010. August 1985 and 2004 experienced exceptional droughts with SPI values of −2.39 and −2.05 respectively. These were the two driest months in the one–month timescale dataset. August 1983, 1991, 1999, 2006 and 2011 had positive SPI values indicating wet conditions despite the fact that most farmers argue that August coincides with the *Kuon Rodow Prang* dry spell. November 1987, 1996, 1998 and 1999 were wet.

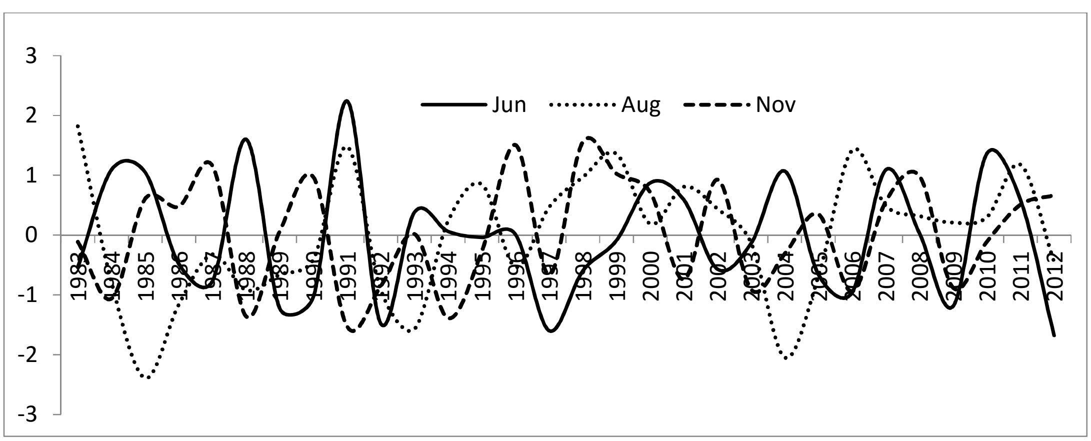


Figure 3.3: One–month SPI values for June, August, and November for Kampong Speu station, 1983–2012.

Two–month timescale: Figure 3.4 shows two–month SPI values. An exceptional drought was identified in the aggregated May and June precipitation data for 1997 (SPI = −2.35); and there were moderate May–June droughts in 1986, 1992, 1998, 2002 and 2005. A severe drought occurred in 1987 and an exceptional drought in 1997. In 1984, 1985 and 2007 May and June were very wet with SPI values of 1.89, 2.56, 1.23 and 1.04 respectively. Aggregated July and August SPI values indicate an exceptional drought in 1993, an extreme drought in 1986, and severe droughts in 1985, 1987 and 2004. The index values for this two–month period in 1983, 1991, 1998 and 2003 suggest very wet conditions. An examination of aggregated October and November data showed that severe droughts occurred in 1994 and 2006, while 1988 experienced a moderate drought. The October–November periods in 1996, 2000, 2001 and 2008 witnessed very wet conditions.

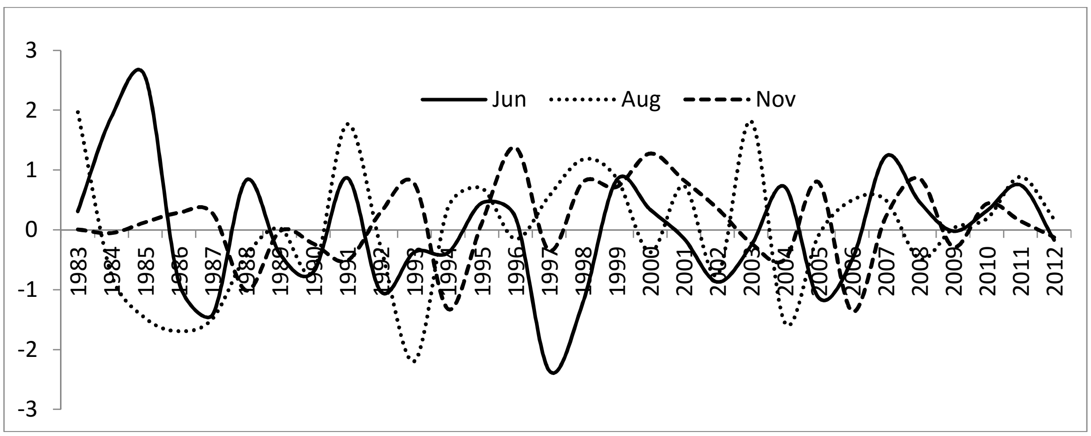


Figure 3.4: Aggregated two–month SPI values based on June, August, and November for Kampong Speu station, 1983–2012.

Three–month timescale: Three–month aggregated SPI values are provided in Figure 3.5. The aggregated precipitation for April–June 1985, June–August 1991, and September–November 1996 indicates that these three–month periods had higher than average rainfall. Extreme droughts over the April–June period were experienced in 1987 and 1997, while other extreme droughts occurred in 1986, 1987 and 1993 (June–August) and 1987 (September–November). No droughts were found in the April–June records. Abnormally dry conditions in the late wet season, i.e. September to November, characterised 1988, 1990, 1991, 1994, 2003 and 2004.

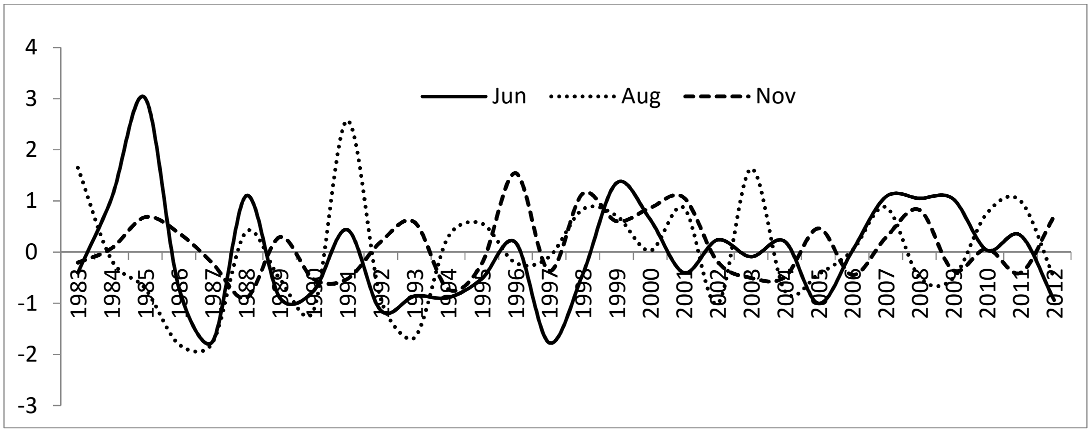


Figure 3.5: Aggregated three–month SPI values based on June, August, and November for Kampong Speu station, 1983–2012.

3.7. Drought, Rice Damage and ENSO Relationships

3.7.1. SPI–defined drought and paddy rice damage

To examine the relationship between drought (defined by the SPI) and paddy rice losses, areal estimates of rice damage in the province were obtained from the Ministry of Agriculture, Forestry, and Fisheries (MAFF). The following analysis and discussion focuses on the period between 1994 and 2011—the years for which consistent and rigorous assessments of rice harvests were made. These data are only available from 1994. Only fragmentary information on drought damage exist prior to this and were not used.

The areas of paddy rice damaged in the province by drought are given in Table 3.3. The extensive drought of 2004 affected over 38,000 ha of rice, equivalent to approximately 46 percent of the normal area cultivated. This drought damaged an area almost 200 times larger than the next most extensive drought, and can mainly be attributed to a severe failure of rainfall in the middle of the growing season. This extended into lower than average rainfall for the remainder of the year. The next most extensive drought—1994—and the five droughts that each caused over 1000 ha of damage (Table 3.3) were associated with drought in only one part of the growing season, though the part of the cropping cycle in which the rains failed was not the same in each case. In 1994, 2003 and 2006 lower than average rainfall was confined to the end of the growing season. In 1997 water deficits occurred very early in the year, while in 2002 dry conditions occurred in the middle of the growing season. The third largest area damaged, 4,744 ha, occurred in 1995. However, it is not related to a low SPI (drought) at Kampong Speu station.

SPI was tested as a drought indicator in Kampong Speu province by assessing its relationship to the drought impact data (Table 3.3) using the critical success index (CSI). The CSI was calculated for one–, two–, three– and 12–month droughts labelled abnormally dry or greater (Monacelli *et al.* 2005), i.e. SPI <= −0.5, and for 1000– and 200–hectare damage thresholds. A CSI of 0.66 (where a perfect prediction is CSI = 1) was achieved for 12–month SPI values of < −0.5 and areal damage greater than 200 ha (Table 3.4) and indicates a strong predictive relationship between SPI–defined droughts and recorded instances of drought–related rice damage.

Table 3.3: Drought–related rice damage in Kampong Speu province and ENSO events between 1983 and 2012.

Year	Damaged area (ha)	Percentage of total cultivated area	Yield (t/ha)	El Niño event at Niño 3.4
2004	38,257	46.26	1.57	Weak
1997	14,962	17.48	2.18	Very strong
1998	14,900	17.81	1.79	Very strong
1994	13,170	16.93	1.52	Moderate
1995	4,744	5.61	2.01	Moderate
2006	2,925	2.69	2.32	Weak
2002	1,498	2.29	1.98	Moderate
2003	1,103	1.16	1.90	Moderate
1999	539	0.62	1.78	None
2009	322	0.29	2.39	None
2012	320	0.29	3.01	Non
2000	223	0.26	1.75	None
2005	63	0.07	2.00	None
2011	53	0.05	3.14	None
2008	49	0.05	1.19	None
2001	16	0.02	1.70	None

Sources: Area and yield estimates are from the Cambodian Ministry of Agriculture, Forestry and Fisheries data. El Niño events are based on the Ocean Niño Index (ONI) from the National Weather Services (National Oceanic and Atmospheric Administration 2015): a weak event is defined as a 0.5 to 0.9 SST anomaly, moderate 1.0–1.4, strong 1.5–1.9 and very strong ≥ 2.0.

The longest drought in the dataset lasted from June to November 2004 and caused the most damage. Even though it only ranged from moderate to severe in intensity according to the SPI values, its duration would have led to a significant depletion of soil moisture reserves and limited recharge. As a consequence it was much more damaging than shorter, more severe droughts, e.g., 1997 and 2006. In light of the significant levels of damage witnessed in 1994, 2003 and 2004, it appears that a reduction in rainfall at the end of the growing season is more deleterious in terms of

rice production than at other times of the year. In 1997 severe to extreme drought occurred early in the rice–growing season, but farmers were able to replant rice seedlings and still reap a reasonable harvest. The 1994 and 2006 droughts that affected the final months of the growing season are more difficult to explain. In both years drought severity peaked before November and this might have allowed some replenishment of soil moisture in time for grain–filling before harvest. The droughts with the least areal damage were generally shorter and only moderate in severity.

Table 3.4: Critical Success Index (CSI) for drought and paddy rice damage.

	Damage > 200 ha	Damage <= 200ha	Total SPI
SPI <=-0.5	10	3	13
SPI > -0.5	2	4	6
Total Years	12	7	19
CSI:	0.66		

3.7.2. SPI–defined drought at Kampong Speu station and ENSO

Understanding ENSO behaviour is critical to understanding indicator–driven Cambodian climate definitions, as is the case in the rest of Indochina (Chang 2004). Pearson product–moment correlation coefficients were computed for SPI values for different time periods for Kampong Speu station and assessed against a range of climate indices that other researchers have argued influence the SEAM. The highest correlations were found for Niño 3.4 (NOAA 2015) lagged by three–months (Table 3.5, Figure 3.6). It is likely that the 12–month SPI values account for overall drought conditions throughout the year and that this leads to higher correlations than SPI values calculated for shorter time periods.

Table 3.5: Correlation Coefficient values for SPI–defined drought at Kampong Speu station and Niño 3.4. All values are significant at p = 0.90.

	1-month SPI	2-month SPI	3-month SPI	12-month SPI
Niño from May to SPI from May	-0.280	-0.372	-0.440	-0.352
Niño from April to SPI from May	-0.219	-0.329	-0.415	-0.376
Niño from Mar to SPI from May	-0.178	-0.288	-0.393	-0.455
Niño from Feb to SPI from May	-0.170	-0.274	-0.377	-0.455

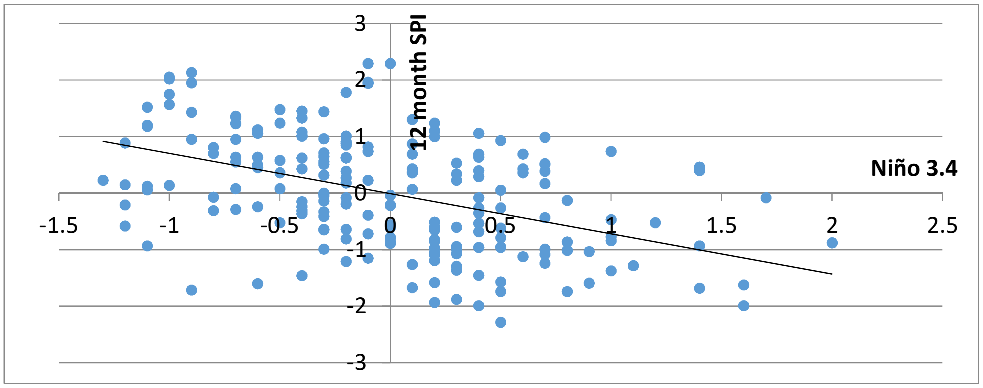


Figure 3.6: SPI values for growing season months (i.e. May–November) and Niño 3.4 data: 1983–2012.

3.7.3. Linking ENSO, local SPI–defined drought and rice damage in Kampong Speu Province

The results above indicate that SPI–defined drought years (based on the Kampong Speu station data) are strongly associated with droughts that cause significant damage to paddy rice; and that the 12–month SPI values are significantly correlated with major El Niño events (Table 3.5, Figure 3.6). These results also show that the impact of a drought on the rice harvest is dependent on (i) when a dry spell occurs during the growing season, and (ii) its duration. Single–month SPI–defined droughts early in the growing season do not lead to large harvest losses, probably because farmers are able to transplant more rice seedlings of short–, medium– and/or long–duration varieties. However, if early season droughts extend beyond a month, significant crop damage can occur. For example, the two–month SPI–defined drought in 1998 destroyed 14,900 ha of rice in the province. This particular early–season drought can be linked statistically to the weakening of an ENSO event in May 1998 (Wolter & Timlin 1998). In 1997 and 2005, the areas destroyed by drought were very different—14,962 and 63 ha respectively—though both of these early season droughts were two to three months in length. However, drought in 1997 was more severe than the early season drought in 2005, and can be linked statistically to the ENSO 1997–1998 event.

Like single–month early–season droughts, one–month mid–season droughts (MSD) do not lead to a significant reduction in rice production. It can be argued that this is because by the middle of the growing season fields are normally flooded up to the level of the bund, and will remain waterlogged even if the rains fail for a month. However, if a meteorological drought at this time extends longer than a month, the probability of crop damage increases because fields can begin to dry out. In 2004, the two–month drought over July and August led to fields drying out in August, which in turn led to almost half of the total cultivated area being damaged, even though June rainfall was normal. This

parallels the Niño 3.4 index data, which indicates an El Niño event developed in June 2004 and lasted until January 2005. Because this event extended throughout the rest of the agricultural year it also led to a late season drought (LSD) which probably compounded the harvest losses. As the damage records are not disaggregated by early–, mid– or late–season in Cambodia, the large amounts of damage cannot be unambiguously assigned to either the MSD or LSD in 2002; in reality they are likely to be a combination of middle and late season water deficits. However, in 2004 a MSD led to significant damage with 1400 ha of rice being destroyed, even though there was no LSD.

Late season droughts cause most damage to paddy production regardless of their duration. In 1994 an LSD lasted three–months and caused approximately 13,000 ha of damage. This drought is evident in the Niño 3.4 data and corresponds to the weak EASM during 1994 (Park & Schubert 1997). The LSD in 2003 is also statistically linked with an El Niño event, although it was only of moderate severity (Logan *et al.* 2008). It was associated with a three–month SPI–defined drought at Kampong Speu station that led to 1,103 ha of paddy damage in the province. In both 2003 and 2004 the rains ceased earlier than usual in the final months of the wet season. The LSD in 2006 was shorter than those in 2003 and 2004 (as indicated by a one– and a two–month, but a three–month, SPI–defined drought). The lower than normal rainfall is likely linked to the weak ENSO event in 2006. There is a high probability that rice losses due to droughts late in the monsoon are related to the fact that diminished rainfall toward the end of the growing season compromises rice grain filling because of the lack of available soil water, which in turn depresses yields.

3.7.4. The potential for drought monitoring in Cambodia

Cambodia has not introduced any early warning system for drought even though it has been noted that drought forecasting is urgently required (Te 2007). One motivation for this research was to provide evidence that an index–based approach to drought monitoring was scientifically sound in relation to the prevailing climatology and the damage to rice due to droughts and dry spells. The variation in SPI can be explained well in relation to Niño 3.4 variability and is a good predictor of rice damage. Unlike other indices that require a more comprehensive array of meteorological observations, SPI can be readily applied widely to Cambodian climate stations with their limited range of equipment. The statistical link to ENSO is critical because, as Zhang *et al.* (2002) have argued, monitoring ENSO is more useful in its predictive power than a rainfall index such as SPI because it provides a longer lead time for drought warning.

The SPI calculation is simple as it is based only on rainfall, but does not have the lead time of Niño 3.4. Nonetheless, having more rainfall stations throughout the country, especially one in each commune, would enable a clearer picture of drought severity and the spatial distribution of drought impacts to be measured. That in turn would lead to better understanding of the relationships between EASM variability, drought and rice damage. Therefore, it can be argued that each commune should simply record rainfall in order to improve prediction and monitoring at the local level, as well as reporting the results to provincial and national recording networks. It would be relatively straightforward for commune members to be trained in recording rainfall and calculating SPI on mobile technologies. Monitoring SPI at the commune level, particularly early in the growing season, when more rice may have to be transplanted, and in the grain–filling period, would allow communes to call for drought alleviation measures such as sourcing more rice seedlings or requesting mobile pumping stations.

Nonetheless, there are limitations. If SPI data were to be used as part of a drought monitoring system, the monitoring tools should not be based on climate data alone. Soils data would be necessary. This is because any drought severity thresholds that would need to be set should be location specific because the duration of waterlogging and extent of soil moisture reserves that can be utilised by rice plants will depend on soil properties. There is also a series of issues related to the spatial distribution of any particular drought or dry spell. This can lead to anomalies, for example the November 1998 SPI values for Kampong Speu station were positive, while the province and the entire lower Mekong suffered a drought (Te 2007). Currently, the density of rainfall stations in Cambodia is too low, large geographical areas lack records and rainfall distributions may not be representative. More precipitation stations are required, preferably at the commune level for the reasons identified above. Furthermore, the degree of drought severity calculated by the SPI must be treated with caution as the SPI values change according to the number of data points used in their calculation.

3.8. Conclusion

Rice–damaging droughts in Kampong Speu province can be linked statistically to ENSO through the Niño 3.4 index. The association between ENSO and drought in the province indicates that when the Pacific Ocean warm pool moves westwards drought is likely to occur. Notwithstanding a previous study by the Ministry of Environment (MoE) which argued that flood and drought occurrences in

Cambodia are not always associated with the ENSO events (Ministry of Environment 2001), the findings in this paper are supported by Buckley *et al.* (2010) who argued that a decline in rainfall associated with ENSO events heralded the collapse of the Angkor era. That said, the MoE study has some validity. The 1995 drought, which appears unrelated to any ENSO event in the record, damaged more than 4,000 ha of paddy in KPS. Moreover, the three–month SPI value for this drought was high was at −0.61.

Drought is a significant economic and livelihood hazard in Kampong Speu province. Droughts damaged more than 1,000 ha of paddy rice in seven of the thirteen years between 1994 and 2006. In each case the damage can be explained in terms SPI–defined droughts related to ENSO phenomena. Late growing season droughts are more damaging than early or mid–season droughts.

We argue that drought monitoring is urgently required in Cambodia if the drought alleviation measures that need to taken are to be effective. This is essential to enhance rural production systems and to improve farming household livelihoods, and to enable to the government to achieve its rice export targets.

Acknowledgments

This research was made possible through a doctoral studies grant from the Department of Higher Education of the Ministry of Education, Youth and Sport through the Higher Education Quality and Capacity Improvement Project (HEQCIP) of the Royal Government of Cambodia to Nyda Chhinh. We thank Chea Bora (DWRAM) for sharing rainfall data, and members of the 'Land Lab' at Flinders University for their comments on earlier versions of this paper. We also appreciate the highly constructive comments of the three anonymous reviewers.

CHAPTER 4: DROUGHT RISK IN CAMBODIA: ASSESSING COSTS AND A POTENTIAL SOLUTION

This chapter addresses research objective number two: to estimate the expected costs of droughts in Kampong Speu. The chapter has been published as the following reference and been reformatted to thesis standard including styles, tables, figures, and headings. The content remains exactly the same as the journal article. The journal is open source and copyright permission is not required.

Chhinh, N, Cheb, H & Heng, N 2014, 'Drought risk in Cambodia: assessing costs and a potential solution', *Asian Journal of Agriculture and Development,* vol. 11, no. 2, pp. 1–16.

The longer version of this paper has been published in the following reference:

Chhinh, N, Cheb, H, Bora, C & Heng, N 2015, *Using reservoirs to adapt to drought in agriculture: a cost–benefit analysis from Cambodia*, Economy and Environment Program for Southeast Asia, La Laguna.

The second and third author contributed data collection and the fourth author was the project manager. The writing and analysis was conducted by Chhinh Nyda.

Abstract: The two major natural hazards that threaten Cambodia are flood and drought. Millions of people have been affected by these natural disasters which have put to waste millions of ha of paddy rice lands on which depend the lifeblood of the rural economy as well as that of the whole country. Given the dire consequences posed by drought to the Cambodian economy, and in light of its short– and long–term development plans aimed at poverty reduction, the government has affirmed its priority for agricultural development. Targeting the most vulnerable areas, this study aims to estimate the costs of drought in two communes in the rural Kampong Speu province, and to assess the costs and benefits of rehabilitating an unused water reservoir. The costs of drought are estimated at the household level. Household questionnaires were used to collect data from households from two rice ecosystems (totally rain–fed and supplementary–irrigated) in the Kampong Speu.

The study finds that the expected loss from drought for farmers in rain–fed areas is USD 51.47 per hectare while that for farmers in supplementary–irrigated areas is USD 23.01 per hectare. Looking at the prospects for rehabilitating a totally damaged reservoir, the study reports that at a 6 percent discount rate, the repair efforts will yield a net present value of around USD 914,834.94 and the benefit–cost ratio is 2.18. The rehabilitated reservoir is seen to serve two significant roles, namely: (i) to stabilise and increase rice production since drought susceptibility among farmers is reduced and food security is ensured and (ii) to encourage agricultural diversification.

Keyword index: Drought, Agriculture, Adaptation

JEL Classification: D61, O13, Q15

4.1. Introduction

Drought and flood have been recognised as major natural hazards in Cambodia (Royal Government of Cambodia 2010a; World Bank 2006; World Food Program 2003; Ministry of Environment 2001). These have affected millions of people and destroyed paddy rice fields (EM–DAT 2012), which provide the main source of rural livelihood and serve as the backbone of the Cambodian economy. Due to the country's geography, which varies greatly both in terrain and in proximity to water, the frequency of natural hazards differs from province to province. The three provinces that are most vulnerable to climate change and, therefore, the most prone to natural hazards are Mondol Kiri, Rotanak Kiri, and Kampong Speu (KPS) (Yusuf & Francisco 2010). Of these three provinces, Kampong Speu has been the most severely affected by drought, based on the physical damage, particularly to paddy rice (Ministry of Agriculture, Forestry, and Fisheries 2010).

Cambodian farmers use two different watering methods: rain–fed and supplementary irrigation. Some farmers totally depend on rainfall to water their crops (from here on referred to as rain–fed farmers), while others (which shall be referred to as supplementary farmers) use both rainfall and other sources of water such as reservoirs and lakes. Rain–fed farmers in Cambodia are very vulnerable to drought, and securing water for these farmers is the key to reducing this vulnerability (Chhinh & Cheb 2013).

Drought can be defined in a number of ways, including meteorological (where there are prolonged periods with lower than average precipitation), agricultural (where there is not enough precipitation to meet the agricultural needs of a region), hydrological (where water reserves fall below average), and socio–economic (where the demand for an economic good exceeds supply as a result of water shortage) (UNISDR 2007; Wilhite & Glantz 1985). All definitions of drought have as their entry point the deficits of water for domestic consumption and/or an established economy (McKee *et al.* 1993). Regardless of the definition criteria, the temporal and spatial distribution of rainfall is a key issue of any kind of drought (Heim 2002; Wilhite & Glantz 1985). For instance, in the case of rain–fed paddy rice production, both the total amount and temporal distribution of rainfall are very critical to inputs and productivities (Ros *et al.* 2011). In this paper, the definition of drought is based on the social perception of farmers who view it as the lack of an adequate amount of water to meet their needs.

The Royal Government of Cambodia sees drought as a threat to the Cambodian economy and is focusing on agricultural development as part of their short– and long–term development plans for addressing poverty reduction. For example, the *National Strategic Development Plan Update 2009–2013* shows a commitment to further rehabilitate and construct physical infrastructure so that the agricultural sector, especially paddy rice productivities, will be promoted (Royal Government of Cambodia 2010a). Agricultural experts in KPS support this policy and, in order to deal with the effects of drought, request the rehabilitation of the Kvet Reservoir, an irrigation facility that was deactivated after the civil war. By looking at the communes in KPS that are most vulnerable to drought, this study aims to investigate the annual economic cost of drought on rice production in both rain–fed and supplementary rice ecosystems and to do a cost–benefit analysis of the renovation of the Kvet Reservoir in the Peang Lvea commune in the Odongk district of the Kampong Speu province.

4.2. Methods

In a rain–fed paddy rice ecosystem, wet season paddy rice production usually runs from May to November. If there is good onset rainfall (i.e., if the rains arrive at the expected time in the expected amount), farmers cultivate a late–maturing variety[4], which is the variety they have traditionally used. If there is less than average rainfall between May and July, they will cultivate an intermediate– and/or early–maturing variety (Figure 4.1).

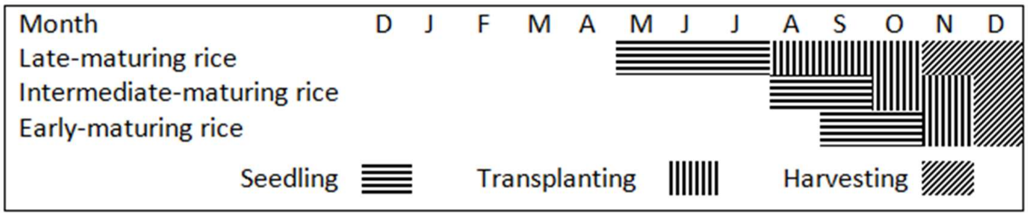


Figure 4.1: Kampong Speu paddy rice crop calendar.

The rice variety most prone to drought is the late–maturing one, which can be affected in a number of ways. If a drought spell of more than two weeks occurs during August, the young seedlings will be damaged. When this happens, farmers have to restart their paddy production using intermediate– or early–maturing varieties. If low rainfall distribution occurs throughout the cropping season, it results in a low yield. Finally, the cultivated area will be reduced if rainfall ceases prematurely before October.

Intermediate– and early–maturing rice varieties are least prone to drought. Farmers cultivate these varieties during late August and September when the soil throughout the country is full of moisture. However, no matter the rice variety, the early cessation of rainfall will adversely affect the rain–fed paddy ecosystem area (as shown in Table 4.1).

Table 4.1: Potential drought impact on rain–fed rice ecosystems in Cambodia.

Drought	Varieties	Seedling	Transplanting	Yield	Area-Harvest
Early-season	Late-maturing	Yes	Yes	Yes	Yes
Mid-season	Intermediate-maturing	No	No	Yes	Yes
Late-season	Early-maturing	No	No	Yes	Yes

[4] The ten rice varieties promoted by the Royal Government of Cambodia since 2011 range from early–maturing to late–maturing types. The three early-maturing varieties are: Sen Pidao, Chul'sa, and IR66; the four intermediate-maturing varieties are Phka Rumdoul, Khka Romeat, Phha Romdeng and Phka Chan Sen Sar; and the three late-maturing ones are Riang Chey, CAR4, and CAR6.

4.2.1. Costs of drought

Wilhite and Glantz (1985, p. 118) identify three kinds of impacts from drought, namely: economic, social, and environmental impacts, which correspond to loss, cost, and damage. Logar and van den Bergh (2012) examine the literature and find that there are three types of drought costs: direct, indirect, and non–market (intangible) costs. While Wilhite and Glantz categorise the kinds of drought impacts and link them with groups or individuals, Logar and van den Bergh monetise costs based on the order of impacts. For example, the direct cost of drought in agriculture is the reduction of crop production. In this study, the costs of drought, which are calculated at the household level, consist of (i) the interruption cost, as seen in the increase in labour and inputs; (ii) yield reduction or low productivities cost, despite the additional labour and inputs; and (iii) the damage cost, wherein the harvested area is smaller than the cultivated area.

The interruption cost is incurred when good onset rainfall is followed by a drought spell during the middle of wet season rice, thereby forcing farmers to increase their labour and inputs for their paddy rice production. In this cost category, farmers cultivate their paddy field twice but harvest only once. This cost, which covers the additional expenses for cultivation–ranging from preparing seedlings to transplanting is usually ignored in the literature. However, the second type of costs, yield reduction caused by drought (i.e., water constraints throughout the cropping season), is often discussed in the literature, for example in Helmers and Jegillos (2004) and the Ministry of Environment (2005b). Lastly, the third type of cost is incurred when there is early rainfall cessation, which destroys the crops and reduces the size of the harvested area compared to the cultivated areas. These data are well recorded by local authorities and the province's Department of Agriculture.

The costs of drought for rain–fed farmers can be estimated temporally depending on the nature of drought, that is, whether the drought occurs in the middle of the wet season rice production; or water constraints characterise the entire cropping season; or the rainy season ceases prematurely. If any of these events occur, the year is called a drought year.

Over the longterm, the annual expected cost[5] (*AEC*) of drought to rain–fed farmers is higher than that for supplementary–irrigated farmers (Equation 4.1). The costs of drought faced by farmers with

[5] This is also referred to in the literature as *expected costs avoided* (ECA).

access to supplementary irrigation can be estimated based on the indication of the nature of drought from the rain–fed location.

$$AEC = \text{(annual probability of drought)} \times \text{(costs in drought year)} \qquad (4.1)$$

4.2.2. Assessing the development alternative

Chhinh and Poch (2012) conducted focus group discussions with local authorities to identify a number of drought adaptation options that would reduce the vulnerability of farmers to the changing climate in the rural areas of Kampong Speu. The most common method identified was securing water for paddy rice production through another water source such as a water reservoir, pumping machine, and/or a tube well. From their findings, they concluded that providing irrigation systems for farmers in rural Kampong Speu was necessary and urgently required.

In the case of normal temporal rainfall distribution, irrigation (for example, from water reservoirs) may not provide any benefits to paddy productivity as farmers are able to cultivate their crop according to the calendar[6] – the rice plant grows normally until harvest time and the crop yields are as expected. However, due to natural hazards caused by climate change effects, farmers, especially those who depend on rain–fed rice production, are no longer able to rely on normal temporal rainfall distribution and must adapt their farming methods and materials to changes in the weather. If there is late onset or lower amounts of rainfall during the starting period of the cropping season, farmers must either delay their crop calendar or transplant the seedlings to their paddy field without water and hope that rain falls in the following days, risking the destruction of the new plants. Many farmers in Cambodia report having experienced these conditions (Chhinh & Poch 2012). Therefore, water reservoirs can play a very significant role in providing supplemental water during the growing period when there are inadequate amounts of rainfall. The water reservoir thus allows for the avoidance of costs associated with drought and enables farmers to start their cropping season according to the time required by the preferred rice variety.

Currently, if supplemental water is needed in rice fields where there are no irrigation systems, water is pumped from nearby small ponds and underground water sources. This practice, however, cannot alleviate severe and widespread drought because the area of paddy that can be watered is relatively

[6] Late-maturing varieties take six months, with sowing done in May/June and harvesting in Nov/Dec. Intermediate-maturing varieties take four months, with sowing in Aug/Sept and harvesting in Nov/Dec. Early-maturing varieties take three months: from May to July in the early wet season, and from January to March in the late wet season.

small in scale. On the other hand, the reservoir, as a supplemental water source, will generate benefits for local communities during the dry season, especially for domestic usage in rural Cambodia (i.e., home gardening, double cropping, aquatic culture, and livestock raising. It may also provide indirect benefits such as improving sanitation in rural Cambodia.

Table 4.2: Potential drought impact on rain–fed rice ecosystems in Cambodia

Revenue	Net Revenue (USD per Hectare)		
	Non-drought year	Drought year	Drought costs
Rain-fed	350	100	250
Supplementary irrigation	550	450	100
With/Without	200	350	-

Source: Modified from Callaway (2003).

In assessing the benefits of using reservoirs to mitigate drought, the costs of drought should be compared as follows: (i) between rain–fed and supplementary irrigated rice systems, and (ii) between a drought and non–drought year (see Callaway (2003) for such a climate risk assessment framework and example in Table 4.2).

4.2.3. Costs and benefits analysis

An extended discussion of the costs and benefits analysis (CBA) economic framework can be found in many textbooks (Mishan 2007; Layard 1972). The benefits of using a CBA here, particularly in relation to risk–based studies, are outlined by Mechler (2005), who identifies the following principles of CBA: (i) a 'with' and 'without' approach, (ii) a focus on the selection of 'best option' if there is more than one option, (iii) a societal point of view, and (iv) clearly–defined boundaries of analysis. A CBA, however, becomes more complex once social and environmental issues are incorporated.

Using the 'with' and 'without' approach, it is possible to compare an investment project, for instance, with no water reservoir and one with a water reservoir in a community. Since the costs of construction are incurred during the first few years, and the operation and maintenance during the lifetime of the reservoir and the benefits from the reservoir are distributed into the future, they can be calculated at present value (PV) (Equation 4.2) and net present value (NPV) (Equation 4.3).

$$PV\ (X) = X_t \frac{1}{(1+r)^t} \tag{4.2}$$

$$NPV = \sum_{t=0}^{T} B_t(1+r)^{-t} - \sum_{t=0}^{T} C_t(1+r)^{-t} \quad (4.3)$$

where *X* is the present value of costs (*C*) or benefits (*B*) at time (*t*) at the discount rate (*r*). The project starts from year one (*t=0).*

One of the benefits of CBA is that it is used widely as a decision–making tool by many organisations including the World Bank, government agencies, and private investors. The traditional criteria for evaluation include the NPV, the benefits and costs ratio (BCR), and the rate of return. However, care must be taken when choosing a discount rate, as is extensively discussed in the Stern Review (Dietz 2008; Nordhaus 2007), as well as in considering uncertainty and other aspects such as equity.

The study compares the NPV of two development scenarios (with and without) over a period of 20 years (based on the life span of a water reservoir). The 'with' scenario refers to farm households who have access to supplemented irrigation. We examined two time periods, a drought and a non–drought year, and requested respondents to recall the costs of rice production associated with drought episodes. Two communes representing two rice ecosystems were selected for comparison: the Sopoar Tep commune served as the supplementary–irrigation site and the Peang Lvea commune served as the totally rain–fed site. A household questionnaire was used to obtain information and understand household characteristics.

4.2.4. Sample selection

Chann and Kong (2014) have developed an index that measures the degree of vulnerability in agriculture. With a vulnerability index of 0.53, the Peang Lvea commune is highly vulnerable, while Sopoar Tep is moderately vulnerable with a vulnerability index of 0.44[7]. The main reason for the difference in the degree of vulnerability is because of Peang Lvea' s frequent exposure to drought and its low adaptive capacity to this problem, especially given its smaller irrigated paddy rice areas. With access to irrigation, the Sopoar Tep commune can produce rice twice per calendar year, compared with once per year in Peang Lvea. The average paddy rice yield in Sopoar Tep is 2.5 tonnes

[7] The exchange rates used in this study is 1 USD = KHR 4000 riels.

per hectare, compared to only 1.5 in Peang Lvea. Both communes depend mainly on agriculture, with 76.4 percent of households in Sopoar Tep and 99.2 percent in Peang Lvea working as farmers.

Purposive and random sampling methods were employed to select the study sample. About 400 households from the total populations of the Peang Lvea and Sopoar Tep communes representing two rice ecosystems (one totally dependent on rainfall, and the other one with access to supplementary irrigation) in Kampong Speu were selected to be part of the survey. A total of 200 households were chosen from each ecosystem at the selected study sites. All enumerators were trained by the research team before conducting actual fieldwork to strengthen the quality of the collected data.

4.3. Research Result

The household survey results show that the respondents in the Peang Lvea commune hold 209 ha of land collectively, while the total cultivated land for 200 respondents in the Sopoar Tep commune is 129.1 ha. Farmers in Sopoar Tep have access to supplementary irrigation while those in Peang Lvea depend on rainfed cultivation. It is important to note that the supplementary irrigation, which allows farmers to combat the effects of drought in both wet season and dry season rice production, also allows farmers to have two crops every year.

4.3.1. Production costs in both rice ecosystems

The production cost is generated from the four stages of rice production: seedling, transplanting, post–transplanting or pre–harvesting, and harvesting. The seedling stage covers preparing the land, purchasing rice seeds, sowing rice seeds, and pulling seedlings. Transplanting covers the labour cost of transplanting and some inputs such as fuel, cost of pumped water, and fertilizers. The growing stage covers the application of some inputs such as fertilizers, pesticides, pumped water, and labour. Lastly, harvesting covers the labour cost for harvesting and transportation.

The calculation of inputs and labour in the two rice ecosystems uses constant prices in both non–drought years and drought years. Notably, the labour cost in both communes will be the same. For example, four hours of labour costs KHR 10,000 per person (about USD 2.5)[8]. To generate the total production cost, the labour contributed by each household (own labour) is also included. Farmers

[8] Own labor is calculated by multiplying the hours worked by the market price (KHR 2,500 per hour or KHR 10,000 for four hours).

in Peang Lvea employ only their family members as labour in the four stages of rice production. If own labour[9] is not included in the calculations, the production cost in Peang Lvea is far below the production cost in Sopoar Tep.

Remarkably, almost all farmers in Peang Lvea use traditional tools for cultivation; for example, they use cattle to plow the land and manually harvest the products. Farmers in Peang Lvea believe that if they employ machines for cultivation (such as hand tractors and harvesting machines), they will lose 40 percent of their output to cover the cost of the new technology. Unlike farmers in Peang Lvea, farmers in Sopoar Tep employ technology for their rice production, especially harvesting machines. That is why the productivity in Peang Lvea is much lower than in Sopoar Tep.

It was found that among the four stages of rice production, the only stage wherein farmers in Peang Lvea invest more than those in Sopoar Tep is the transplanting stage. This is for two reasons. First, most of the farmers in Peang Lvea plow their land twice before transplanting, and second, almost all farmers in Peang Lvea use their own labour to complete farming activities while farmers in Sopoar Tep invest in technology. In general, farmers in Peang Lvea invest less input than farmers in Sopoar Tep. Farmers in Peang Lvea spend KHR 188,500 (USD 47.12) on fertilizers only (not including pesticides) while farmers in Sopoar Tep invest KHR 642,857 (USD 160.71) on both fertilizers and pesticides. In short, it can be said that farmers in Peang Lvea invest in own labour more than Sopoar Tep, while farmers in Sopoar Tep invest more in fertilizers and pesticides than farmers in Peang Lvea.

4.3.2. Impact of drought

The different types of costs incurred by rain–fed farmers due to drought can be estimated temporally. These costs, which arise depending on the nature of the drought, are: interruption cost, when there is early cessation of rainfall; low productivity cost, when drought occurs in the middle of planting wet season rice; and damage cost, when there are water constraints throughout the cropping season.

4.3.3. Interruption costs

There are two possible stages where the rice production process can be interrupted: the seedling and transplanting stages. Each household usually prepares its own seedbed and cultivation

[9] For more technical details, see Mechler (2005).

seedlings for paddy rice cultivation. The likelihood of interruption costs was higher in rain–fed communities than in supplementary irrigated ecosystems. For instance, 52 percent and 35.5 percent of respondents in Peang Lvea experienced the effects of drought during the seedling and transplanting stages, respectively, while only 8.5 and 5 percent of respondents in Sopoar Tep felt the impact of drought during seedling and transplanting, respectively. Therefore, in both communes, a greater number of farmers reported adverse effects in the seedling than in the transplanting stage. This shows that the likelihood of damage is greater in the initial stage.

Farmers found it difficult to recall the number of times they experienced losses during the seedling and transplanting stages of their rice production. There was a general agreement, though, that the damage from drought recurred every four or five years.

4.3.4. Low productivity costs

Low productivities were reported more in rain–fed areas (85 percent of households in Peang Lvea) than in supplementary–irrigated areas (24 percent of households in Sopoar Tep). In the rain–fed area, farmers normally have a yield of approximately 1.5 tonnes per hectare, compared with around 3 tonnes per hectare in supplementary irrigated areas. However, in 2012, the yield was 1.40 and 3.01 tonnes per hectare in Peang Lvea and Sopoar Tep, respectively. The yield reduction due to a drought episode was reported to be about 30 percent in Peang Lvea and 35 percent in Sopoar Tep, based on the household survey. The recurrent period of low yield was reported to be 10 years.

4.3.5. Damage costs

The total area of cultivation during both normal and drought years is 338.1 ha (209 and 129.1 ha in the Peang Lvea and Sopoar Tep communes, respectively). This means that farmers always cultivate their land regardless of whether it is a normal or drought year. However, each commune faced a reduction in the area harvested during drought years, that is, from 209 ha to 57.6 ha in Peang Lvea (an 83 percent reduction) and from 129.1 to 123.3 ha in Sopoar Tep (a 5 percent reduction). There is a sizeable decline in the area harvested during a drought episode in a rain–fed area.

The loss of harvested area in Peang Lvea during a drought year was 72 percent and 82 percent of total production (241.1 tonnes) compared to Sopoar Tep's 4.5 percent of harvested area and 20 percent (66.7 tonnes) of total production. It was reported that farmers experienced this loss in 2004 and remember it occurring once during the last 20 years (1990‑2010).

4.3.6. Expected loss to farmers in rain–fed areas

The total expected loss from drought during the period 1991‑2010 is estimated in this and the following section[10]. The damage costs are estimated based on the premise that there is damage during the seedling and transplanting stages once every five years, yield reduction once every 10 years, and paddy damage once every 20 years. The premise was set based on key informant interviews in the study sites.

In a normal year, the cost of the seedling stage is USD 23,869 (or USD 114.21 per hectare) and the cost of transplanting is USD 46,807 (or USD 223.96 per hectare). Some 52 percent of households in Peang Lvea reported that they had experienced damage during the seedling stage and 35.5 percent reported damage during transplanting. Assuming that these figures also represent the total increase in production costs (borne out of the farmers' need to re–prepare their seedlings and to transplant), the cost increases to USD 12,411.88 for the seedling stage and USD 16,616.49 for transplanting. Hence, in total, the cost in Peang Lvea from damage during the seedling and transplanting stages is USD 29,028.37 per 209 ha in a drought year.

Based on normal yield (1.4 tonnes per hectare in 2012) of rain–fed paddy rice, the total production in Peang Lvea is 292.60 tonnes which is equal to USD 80,465.00 (USD 275 per tonne at farm gate at 2012 prices). During a drought episode, with 85 percent of households reported to experience a yield reduction of about 30 percent, the production will be 217.99 tonnes or equal to USD 59,946.43. The cost of yield reduction is USD 20,518.58 per 209 ha in the drought year.

Finally, the damage to the harvest area is calculated at USD 66,368.50. The total harvested area during a severe drought year was 57.6 ha, with a total production of 51.26 tonnes from the 209 ha of the sample. During the drought episode, farmers could only earn USD 14,096.50, while in the non–drought year farmers could produce up to USD 80,465 (based on a yield in 2012 of 1.40 tonnes per hectare).

[10] There is a separate report that contains the feasibility study for Kvet Reservoir.

Table 4.3: Drought–risk as represented by the loss–frequency function of rain–fed agriculture.

Recurrent period (years)	Annual probability	Damage (USD)	Risk: Prob × damage (USD)
5	0.2	29,028.37	5,805.67
10	0.1	20,518.58	2,051.86
20	0.05	66,368.50	3,318.43
Annual expected damages			11,175.96

The expected loss from drought in the Peang Lvea commune is USD 11,175.96 per annum per 209 ha (Table 4.3). This is based on a recurrent period of different drought intensities that are associated with damage in the seedling and transplanting stages, yield reduction, and reduction in harvested area. The cost of each category is similar in terms of loss–frequency function. The expected loss is USD 53.47 per hectare.

4.3.7. Expected loss for farmers in supplementary irrigation areas

This section presents the estimated results on the expected loss from drought during the period 1990‑2010. As in the rain–fed areas, the damage costs are estimated based on the fact that there is damage to seedlings and transplanting once every five years, yield reduction once every 10 years, and paddy damage once every 20 years.

In the ST commune, the cost from damage suffered during the seedling and transplanting stages is USD 2,357.78 in a drought year per 129.1 ha. In a normal year, the cost during the seedling stage is USD 14,177.76 (or USD 109.82 per hectare), and the transplanting cost is USD 23,053.39 (or USD 178.57 per hectare). Some 8.5 percent of households in ST reported that they have experienced damage to seedlings and 5 percent reported damage during the transplanting. Assuming that these figures also represent the total increase in production costs (as farmers re–prepare their seedlings and transplant), the cost increases are USD 1,205.11 for the seedling stage and USD 1,152.67 for transplanting.

The cost due to yield reduction is USD 9,031.00 per 129.1 ha in a drought year. Based on normal yield in supplementary irrigated paddy rice (3.01 tonnes per hectare in 2012), the total production in ST is 388.59 tonnes, which is equal to USD 106,862.25 (USD 275 per tonne at farm gate in 2012 price). During a drought episode, 24 percent of households reported that they experienced yield reduction (about 35 percent less than in a normal year). Therefore, production will be 355.67 tonnes due to yield reduction, which is equal to USD 97,831.25.

Finally, the cost of the damage to the harvest area is USD 31,924.75. The total harvested area during the severe drought year was 123.30 ha (a reduction from 129.1 ha) with a total production of 272.2 tonnes. During a drought episode, farmers could only produce USD 74,937.50 worth of rice, while in a normal year farmers could produce up to USD 106,862.25 worth.

In the ST commune, the expected loss from drought in supplementary irrigated paddy production is USD 2,970.90 per annum per 129.1 ha. This is based on a recurrent period of different drought intensity levels that are associated with the damage of seedlings and transplanting, yield reduction, and damage to harvested areas. As shown in Table 4.4, the cost of yield reduction is higher than the rest in terms of loss–frequency function. The expected loss is about USD 23.01 per hectare.

Table 4.4: Drought–risk as represented by the loss–frequency function of supplementary irrigation agriculture.

Recurrent period (years)	Annual probability	Damage (USD)	Risk: Prob × damage (USD)
5	0.20	2357.78	471.56
10	0.10	9031.00	903.10
20	0.05	31,924.75	1,596.24
Annual expected damages			2,970.90

The difference in expected loss per hectare from drought events in rain–fed (USD 53.47) and supplementary irrigated (USD 23.01) areas is USD 30.46.The difference in expected loss is relatively large because PL is more sensitive to changing rainfall and therefore experiences a greater loss in production than ST. Also, there is a big difference in the productivity levels of rain–fed and supplementary irrigated areas. For example, ST yields twice as much as PL. Also, PL and ST are affected differently by drought in terms of the reduction in the harvested area.

4.3.8. Water reservoir feasibility study

Cost analysis of the renovation of the Kvet reservoir

Attempts have been made to supply farmers in the Kampong Speu province with water, especially in the Peang Lvea commune. This study investigated the cost of renovating the Kvet reservoir, an old reservoir built during 1975‑1979 in the Peang Lvea commune. Portions of the reservoir are currently being used to cultivate rice. The land surrounding it is barren and has been set aside for restoration.

Based on our feasibility study, the primary costs of the rehabilitation of the reservoir include renovating the 1,150 metre dike, renovating the 4,000 metre canal, removing and reconstructing

one large water gate, and constructing culverts with gates[11]. The water is supplied to paddy rice using gravity. The total engineering cost is USD 343,680.

It is estimated that USD 21,204 will be spent annually for operation and management (USD 36 per hectare). To increase the skills of farmers in PL to be on par with those in ST, agricultural extension services will be provided to them at the cost of USD 26.40 per hectare or USD 15,547 in total.

Additionally, the renovation of the Kvet reservoir will result in a loss to the farmers who currently cultivate their paddy rice in the water reservoir. According to the engineering study, 49.56 ha of public land would no longer be available for cultivation after the renovation. Assuming that 49.56 ha could produce 1.40 tonnes of rice per hectare, the total production in the current cultivated land in the reservoir is USD 19,081 annually.

In sum, the total cost of renovating the Kvet reservoir comprises the engineering cost of renovation, the operation and maintenance cost, the agricultural extension service, and the opportunity cost of the cultivated land in reservoir. Specifically, the cost in year 0 is USD 362,761, while the cost in years 1 to 19 is USD 36,751 per year.

Benefit analysis of the renovation of the Kvet reservoir

According to our feasibility study, the Kvet reservoir could supply water to 324 ha of cultivated land in the wet season, 75 ha in the dry season, and 190 ha in early– season rice production. The 324 ha include the 209 ha of the paddy fields owned by households which participated in the survey.

If there is a water reservoir in Peang Lvea, the expected loss during drought events of the Sopoar Tep commune is transferred to the estimated expected loss against the whole area (324 ha), meaning that if the 324 ha of paddy area of PL is irrigated like in ST, farmers will lose only USD 7,455.24 instead of USD 17,324.28[12] instead of USD 17,326.8 (or a difference in amount of USD 9,850.23). This value is then treated as the avoided damage cost that is provided by the facility. At the same time, the productivity of the wet season is expected to increase from 1.40 to 3.01 tonnes. The net revenue of wet season rice will increase by USD 392.59 (from USD ‑361.33 in Peang Lvea to

[11] This value (USD 7,455.24) is from 324 ha x USD 23.01 (expected drought damage costs in ST).

[12] The value (USD 17,324.28) is from 324 ha x USD 53.47 (expected drought damage costs in PL).

USD 31.26 per hectare in Sopoar Tep for 324 ha of wet–season rice), which comes up to about USD 127,199.16 per 324 ha of irrigated land.

The feasibility study finds that the reservoir can supply 75 ha of dry–season rice and 190 ha of early–season rice, with the additional areas also estimated as part of the feasibility study. This assumes that even during a drought year, there will be no impact on dry–season and early–season rice, and the net revenue is the same as ST in dry–season rice and wet–season rice (USD 70.18 and USD 31.26 per hectare, respectively). Therefore, the dry season rice and early–season rice production will enable farmers to gain USD 5,263.50 and USD 5,939.40, respectively.

To summarise, the total benefit of the project is USD 148,271 per year, including avoided damage cost, increased productivity, and the benefit of dry–season rice and early–season rice. This benefit would occur from year 1 to year 19.

Cost benefit analysis and its sensitivity analysis

With the rehabilitation projected to begin in 2014, the reservoir should be functional and therefore start yielding benefits from 2015. The projected costs include USD 362,761 in Year 0 (to cover the first year of construction and the opportunity cost of cultivated land in the reservoir) and USD 36,751 from Year 1 onward (to cover operation and maintenance, agricultural extension service, and the opportunity cost of cultivated land in the reservoir). The benefits, yielded from the first year, are the avoided damage costs based on annual expected damage and the increasing yield from supplementary irrigation and double cropping. The total benefit is USD 148,271. In order to complete the CBA and sensitivity analysis, four scenarios are generated: a good scenario (Scenario 1), a bad scenario (Scenario 2), a worse scenario (Scenario 3), and the worst scenario (Scenario 4).

A good scenario is generated with the assumption that the project is under perfect estimation. In other words, there is no change from the analysis. As shown in Table 4.4, in this scenario the project generates USD 914,834.94 as net present value for 20 years, where the benefits are higher than costs 2.18 times. Figure 4.2 also illustrates that even when the discount rate increases to 14 percent, the project could generate USD 376,000 over 20 years.

A bad scenario (Scenario 2) is formulated by assuming that the project cost is underestimated by 15 percent or that the project cost could increase by 15 percent of the total cost of the project. Under this scenario, the project only earns USD 798,910.00 as net present value and has a benefit 1.9 times

higher than cost with an internal rate of return (IRR) of 25.13 percent. If the discount rate increases to 14 percent, the project could earn USD 285,000 (Figure 4.2).

Table 4.5: Calculation of the costs and benefits of the rehabilitation project.

BCA	Scenario 1	Scenario 2	Scenario 3	Scenario 4
NPV	914,834.94	798,910.00	661,684.76	545,759.82
BCR	2.18	1.90	1.86	1.61
IRR	30.60%	25.13%	24.30%	19.54%

The worse scenario (Scenario 3) results from the assumption that drought would destroy 15 percent of the total benefit. If cost is constant but 15 percent of the benefit is reduced by drought, the project could earn USD 661,684.76. Therefore, the project could get 24.30 percent of IRR with a benefit 1.86 times higher than cost. In case the discount rate increases to 15 percent, the project will still manage to generate USD 229,000.

Finally, with the worst case scenario (Scenario 4), it is assumed that the project underestimates 14 percent of the cost, and that 15 percent of benefits are decreased by drought. Even in the worst case, the project does not lose under the discount rate of 6 percent. In this scenario, the project could earn USD 545,759.82, with the benefits 1.61 times higher than the cost, and its IRR is 19.54 percent. Although, under the worst scenario the discount rate decreases to 14 percent, the project still provides benefits. Under a discount rate of 14 percent in the worst scenario, the project could earn USD 138,000.

Assuming the discount rate of 6 percent is correct and the benefit is constant, the profit is still positive if the cost is underestimated by less than 15 percent. If the cost of the project is constant with a 6 percent discount rate, the project is still beneficial if the benefit decreases by less than 15 percent. In all scenarios, the project provides benefits for paddy rice cultivation.

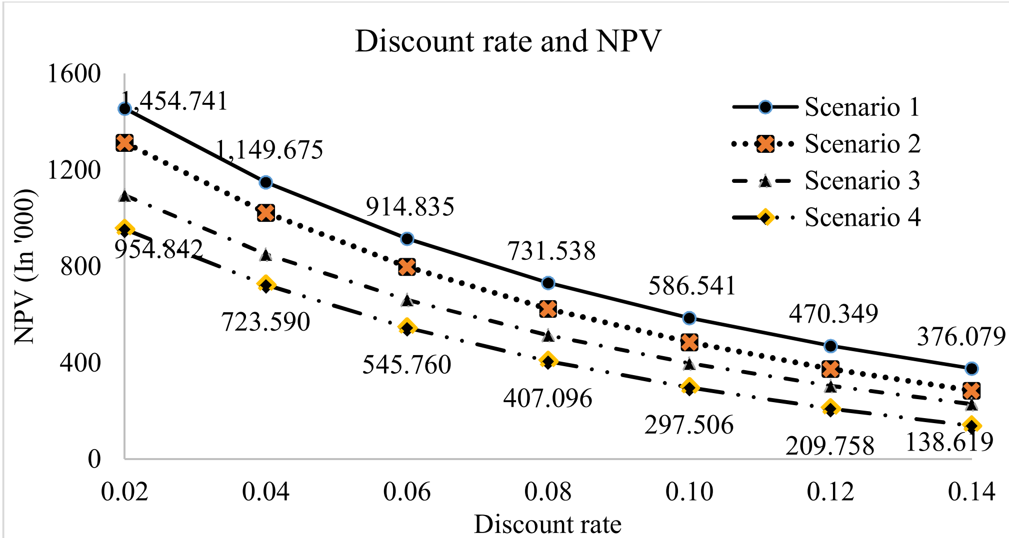


Figure 4.2: Sensitivity analysis of the Kvet Reservoir project.

4.4. Discussion

The Stern Review estimates that the annual cost from climate change impacts is approximately 5 percent of the world's GDP, and, in the worst cases, the damage cost could jump to 20 percent or more (Stern 2006). This study finds that the expected loss to a rain–fed farmer during a drought year is USD 53.48 per hectare. At a 6 percent discount rate, the rehabilitation of the Kvet Reservoir will yield a net present value of USD 914,834.94 (Table 4.5). Also, its benefit–cost ratio of 2.18 is high. Rehabilitating the reservoir will help to provide water and food security for smallholder farmers in rural Cambodia, and is the most effective project proposed to date. For example, a study by Barker and Molle (2004) found that the trend of benefit–cost ratio of irrigation investment in the Philippines and Sri Lanka diminished between the 1970s and the 1990s from the highest number (more than 3.5) to the lowest number towards the end of the study period (less than 0.5). The benefits calculated in Table 4.5 do not take into account other incidental benefits, such as protecting non–rice crops such as watermelon.

In the rural livelihood context of Cambodia, irrigation is often viewed as providing water security and is closely linked with food security, the cost benefit analysis on irrigation in this paper primarily focuses on profits, especially measurable ones. While the latter perspective produces quantitative values that are useful for policy makers (which they often prefer), the former viewpoint highlights social welfare and, more importantly, the survival of the rural, small–size paddy farmers who are highly dependent on subsistence farming.

By default, farmers will do everything in their capacity to maintain their yield, and while rice yield declines may not be recorded, the cost of operating their farms increases during all intensities of drought. Therefore, the observed yield fluctuation may not be associated with drought (rainfall) but may be related to other factors such as lack of labour, an increase in the price of fertilizers (which may also happen during years with good rainfall), and a resultant decline in yield. Thus, since drought is a creeping phenomenon which is often hard to identify, in the event of drought, the hardship experienced by farmers is increased before any interventions occurs.

4.5. Conclusion

In Cambodia, the biggest concerns resulting from climate change impacts are flood and drought. Drought occurs frequently in Cambodia and its impact is felt by many, especially the rain–fed farmers in the Kampong Speu province whose livelihood is heavily dependent on agriculture. Recognising that agriculture is the backbone of the economic sector, the Royal Government of Cambodia is implementing methods to mitigate drought, especially through improvements in physical infrastructure such as installing water reservoirs. Within the government's climate change projects, there are nine projects aimed at mitigating drought and five projects to mitigate the effects of flood. All of the drought projects are focused on irrigation, such as water reservoirs.

Households in Kampong Speu often experience drought. Rain–fed farmers are highly vulnerable to climate variability and interventions are necessary and urgently required, especially in relation to agriculture. It is socially and scientifically agreed that Cambodia will experience more drought in the future; therefore securing water is vital to avoid widespread crop failure and the resultant hardship and poverty.

This study found that farmers experienced drought one to four times between 1990 and 2012. Drought was defined based on the farmers' experiences of water shortages in their paddy fields resulting in damage to seedlings, yield reduction, or the destruction of paddy rice. The degree of severity of drought experienced was different for farmers located within the range of supplementary irrigation from those who were totally reliant on rainfall, with both the drought recurrent period and the degree of impacts from drought higher in the rain–fed paddy rice area. Without supplementary irrigation, data suggested that there was a reduction of at least 73 percent of paddy production compared with a non–drought year. It was estimated that farmers in rain–fed areas faced an annual expected loss of USD 53.48 per year for every hectare of paddy field.

After conducting a feasibility study of the Kvet Reservoir (an unused reservoir located in the Peang Lvea commune), we found that the costs of the investment on rehabilitation are low compared with the benefits. If rehabilitated, the reservoir will play a very significant role in food security, as the majority of households in the Peang Lvea commune are subsistence farmers who own very small areas of land. One season of crop failure spells long–term disaster for many households. Therefore, it is imperative that the rehabilitation of the reservoir be started as soon as possible before irreversible consequences happen in the community.

Acknowledgements

This work was carried out with a grant from the International Development Research Centre (IDRC) in Ottawa and the Economy and Environment Program for Southeast Asia (EEPSEA). I would like to thank Dr. Herminia Francisco for her advice; Dr. Bui Dung The Dr. Benoit Laplante and reviewers for technical comments; the Department of Higher Education for funding my PhD study under the Higher Education Quality and Capacity Improvement Project (HEQCIP); Flinders University where Nyda Chhinh is doing his PhD Course and, last but not least, to the survey respondents.

CHAPTER 5: CLIMATE CHANGE ADAPTATION IN AGRICULTURE IN CAMBODIA

This chapter addresses research objective number three: to discuss potential solutions through monitoring and/or mitigating droughts in Kampong Speu and Cambodia. The chapter has been published as the following reference and been reformatted to thesis standard including styles, tables, figures, footnotes and headings. The content remains the same as the chapter of the book with copyright permission Ref: P.3028 by Ruth Atherton.

Chhinh, N 2014, 'Climate change adaptation in agriculture in Cambodia', in S Vachani, (ed.), *Adaptation to Climate Change in Asia*, Edward Elgar, London, pp. 163–182.

Agriculture is a critical component of the Cambodian economy but agricultural production is frequently disrupted by flood and drought, which are likely to worsen due to climate change. This chapter provides an overview of the broad impact of climate change on Cambodia and, more specifically, the occurrence of flood and drought and their impact on paddy rice production in Cambodia. It then discusses current adaptation practices and policy interventions in the context of climate change by the Royal Government of Cambodia (RGC).

5.1. Impact of Climate Change in Cambodia

The Ministry of Environment (2001) projects that climate change is going to alter Cambodia's rainfall in the wet season (May–November) as well as the dry season (December–April). It has used a Global Circulation Model to examine Cambodia's rainfall pattern and predicts that rainfall will vary up to 794 mm in the wet season. The finding of the Ministry of Environment (2001) is echoed by McSweeney *et al.* (n.d). They employed three climate change models to study Cambodia's rainfall patterns and find that climate change will result in increased rainfall between 0 to 14 percent during the wet season and reduced rainfall during the dry season.

While the projection is made for the future climate of Cambodia, the cascading impact of climate change effects, especially the change in rainfall intensity and frequency, have already provided challenges for Cambodia's people and the country's development.

Paddy production has been impacted greatly by flood and drought. The distribution of average rainfall in Cambodia is between 1,000 mm to 4,000 mm per annum. Within the paddy rice production area in the flood plains, the rainfall is between 1,000 mm and 1,600 mm per annum. The terrain of Cambodia is often compared to a frying pan, with highlands and mountain ranges surrounding a flat country. This creates huge flood plains around the Tonle Sap Lake and Mekong catchment. The Bassac River and the Mekong River systems potentially provide Cambodia with plentiful water for agriculture, especially paddy rice. However, the combination of a lack of physical infrastructure and the temporal and spatial shift in rainfall distribution in that area will spell disaster for agricultural production from both drought and flood.

The impact of climate change will intensify the hardship of people who are dependent on natural resources. Rainfall that has temporally shifted from the dry season to the wet season (McSweeney *et al.* n.d) will unbalance the discharge of the Tonle Sap Lake and result in saltwater disturbance in the Mekong delta area, which could disrupt agricultural production and cause damage to the social

and physical infrastructure and ecosystems (Vastila *et al.* 2010; Varis & Keskinen 2006). The Tonle Sap Lake currently supports 2 million people directly and more than 6 million indirectly. When the shifting rainfall patterns are combined with large dam construction within the Mekong River basin, the Tonle Sap Lake's ecosystems are highly vulnerable (Benger 2007). It is believed that the Tonle Sap Lake is prone to climate change and the current capacity of the people who live in that area to adapt to environmental shock is weak (Nuorteva *et al.* 2010). Therefore, the intensity and frequency of the shocks can have disastrous consequences for the area and its inhabitants.

The impact of flood and drought in Cambodia has increased due to an increase in both intensity and frequency. The Ministry of Environment (2001) confirms that between 1997 and 2001, rice production loss in Cambodia, one of the main contributors to economic growth, was associated with flood (about 70 percent) and drought (about 20 percent). A sharp decline in income from agriculture between 2001 and 2005 was also attributed to consecutive flood and drought events (Fitzgerald *et al.* 2007). Cambodian farmers have reported that flood and drought events have increased in both frequency and severity (Ministry of Environment & UNDP 2011; Geres–Cambodia 2009; Ministry of Environment 2005b). It is evident that the effects of climate change are tangible and beyond the coping range of farmers. Policy development that will enhance the adaptive capacity of farmers to natural hazards, especially flood and drought that are worsening due to the changing climate, is urgently required.

5.2. Agricultural Context

The majority of the rice–growing provinces in Cambodia are located in a low–lying area called a 'lowland rice area' by agricultural experts. Situated within this region, the Mekong River plain region (which contains the Kampong Cham, Kandal, Phnom Penh, Prey Veng and Svay Rieng provinces) and the Tonle Sap plain region (which contains the Bantey Meanchey, Battambang, Kampong Chhnang, Kampong Thom, Pursat, Siemreap, Oddor Meanchey and Pailin provinces) account for 42 percent and 42.5 percent of Cambodia's total rice production area, respectively.

In Cambodia, rice is not only a staple food but also an economic good. Like many Asians, Cambodians eat rice at every meal. The World Food Programme (WFP) estimates that each Cambodian consumes around 150 kg of milled rice per year (Royal Government of Cambodia 2010b; World Food Program 2003). Cambodia must produce at least 3.5 million tonnes of paddy rice per year to feed its

population of 14 million[13]. In 2009, Cambodia's total production of paddy rice was 7.59 million tonnes and export was expected to be 3 million tonnes after domestic consumption. However, the quantity of milled rice registered as exported was only 13,000 tonnes (Royal Government of Cambodia 2010b). Seeing rice as 'white gold' and a major growth opportunity for Cambodia, the RGC committed to turn the country into a 'rice–basket'. Rice is an important component of agriculture, which along with fisheries and forestry accounts for 28 percent of gross domestic product (GDP) (National Institute of Statistics 2008b). The share of services in the GDP is 38.3 percent, while that of industry is 28.6 percent. Unfortunately, rice production in Cambodia has faced many challenges.

The challenges in promoting agricultural productivity, mainly rice production, for farmers can be grouped into four categories: low capacity of farmers, high input cost, unstable output price and inadequate agricultural development.

5.2.1. Low capacity of farmers

Low productivity may be due to the low capacity of farmers to adapt to climate change. Cambodia's rice yield is comparatively low at around 2 tonnes per hectare. Vietnam and Thailand, in comparison, each produce approximately 3 tonnes per hectare (Yu & Fan 2011). As pointed out by Yusuf and Francisco (2010), Cambodia is vulnerable to climate change due to low adaptive capacity when exposed to natural hazards such as drought and flood. This low capacity of farmers can be due to farming techniques, inadequate investment and environmental reasons, such as rain–fed cultivation and poor soil.

In terms of farming techniques, farmers are still using traditional cultivation practices. A study by the Ministry of Environment (2005b) could not identify any measures taken by farmers to adapt to flooding other than traditional practices such as planting crops as usual with their traditional variety and moving to higher ground during flooding. Due to the fact that the majority of farmers (47 percent) own less than 1 hectare of agricultural land (National Institute of Statistics 2009), employing modern farming techniques and using good–quality seeds would ensure that enough rice is produced to support household needs (Tsubo *et al.* 2009). However, there is slow adoption among farmers of modern farming techniques such as Systematic Rice Intensification (SRI) (Sovacool *et al.*

[13] Cambodia's population in 2010 was 14 million (National Institute of Statistics 2008a).

2012; Ministry of Agriculture, Forestry, and Fisheries 2011). According to Yu and Fan (2011), farmers who are trained in modern farming techniques yield about 16 percent more than those who are not. Cambodia's Centre for Study and Development in Agriculture (CEDAC) claims that improved knowledge about water and weed management, combined with planting different varieties of rice and using natural fertilizers, which farmers can make by composting, would double rice yield (Cambodia Center for Study and Development in Agriculture 2011). However, this approach is not frequently adopted in Cambodia (Deichert & Yang 2001). The number of farmers who did adopt it increased from 28 in 2000 to about 60,000 in 2006 (out of a total of 1.8 million farming households) (Yang 2012). This slow rate (as claimed by Yang 2012) of take–up may be due to the increased labour intensity required for the new techniques. For example, water management for the SRI technique needs more monitoring and training than traditional methods.

Additionally, levels of investment by Cambodian farmers are relatively low. When cultivating rice in soil of poor quality, farmers must use more fertilizer (with appropriate application) to increase yield (Men 2007; World Bank 2006), however, studies show that Cambodian farmers fail to do this (Yu & Fan 2011). White *et al.* (1997) estimate that without fertilizer, soil in Cambodia will yield at maximum between 900 kg and 2,600 kg per hectare.

The productivity of paddy rice in Cambodia is highly sensitive to changing rainfall due to the lack of irrigation systems and dikes to protect crops from drought and flood. About 30 percent of the wet season rice is supplementary irrigated (National Institute of Statistics 2008b). Physical damage to rice production caused by flood and drought is reported every year.

5.2.2. High input cost

Cost of fertilizer, pesticide and fuel, along with land rent, are the major input costs for paddy rice. Nam and Theng (2009) argue that there should be more low–rate loans available for farmers to enable them to invest in their production, stating that each 1 percent increase in correctly used fertilizer leads to a 0.22 percent increase in yield for dry season rice and 0.27 percent for wet season rice. Touch and De Korte (2007) note that pests and disease have contributed to rice yield reduction dramatically and that, at the same time, if farmers use pesticide they can experience problems such as health damage and disability. The cost of pesticides may not be as high as the damage to health caused by pesticide use.

The cost of fuel is also a burden for Cambodian farmers. For example, during drought, farmers need to pump water into their paddy field. When this occurs, some farmers borrow cash at a high interest rate to buy diesel fuel or to hire pumps to irrigate their drying paddy field (McAndrew 1998).

The high rural–urban migration rates have created an agricultural labour shortage and require farmers to change from employing labour to renting machinery, thereby pushing the cost of production higher. In rural areas, there has been an increase in landless farmers who either engage in agricultural wage–labour or rent other people's land to cultivate paddy rice (Kim *et al.* 2002). The land rent is high, which reduces the profitability of cultivating rice (Agrifood Consulting International 2005).

5.2.3. Unstable output price

Farmers are hesitant to invest to increase yield due to the unreliable market price of paddy rice. Many poor farmers face a lack of cash before harvesting. In order to survive, they borrow money for almost all of their needs from middlemen and then have to sell their production soon after the harvest to those middlemen. Agrifood Consulting International (2005) finds that farmers often sell their production at the farm gate at well below the market price. If middlemen are involved in the transaction, the farmer must sell their paddy to the middlemen at an even lower price. Therefore, knowing that their paddy rice price will not be good, they apply a 'safety first' principle, which means that they invest only enough to secure their annual needs and thus compromise yield.

5.2.4. Inadequate agricultural development

There is lack of implementation of agricultural development programmes that promote rice productivity in Cambodia. The agricultural development that the government focuses on includes increasing farmer capacity, intervention on farming input costs and ensuring stable agricultural output prices, which are discussed in detail in Section 5.4.

When farmers' capacity is low (owing to reasons such as poor understanding of techniques, low investment and fragile soil) and government intervention is low, input prices can be high and farmers have difficulty dealing with unstable output prices.

These factors are treated with high priority in the National Development Plan, the major constraints of which are described in Section 5.3. Some government reports on the constraints, especially from the MoE, have confirmed that flood and drought are going to be major threats and require urgent

intervention to address climate change impacts in Cambodia (Ministry of Environment 2005a). Some authors claim that while Cambodia has abundant water in its rivers, lakes and aquifers, the livelihoods and food security of its people are threatened by drought (Turner *et al.* 2009).

5.3. Natural Disasters

The Hyogo Framework for Action 2005–2015 posits that 'disaster risk arises when hazards interact with physical, social, economic and environmental vulnerabilities' (United Nations 2005, p. 1). Natural disasters are closely associated with natural hazards such as drought and flood (Chapman 1994). In the International disaster database[14], maintained by the Centre for Research on the Epidemiology of Disaster (CRED, also known as ED–DAT), the disaster criteria include 'at least one of the following: 10 or more people killed, 100 or more people are affected, declaration of a state of emergency or call for international assistance' (Guha–Sapir *et al.* 2012, p. 7). According to EM–DAT (2012) records, since 1900 Cambodia has experienced flooding 12 times, drought five times and tropical cyclones three times. The provincial–level records, however, contain more information than the CRED data and indicate that these events have occurred much more frequently.

Based on provincial data, Cambodia experienced flooding 20 times between 1984 and 2011 and flood has caused damage to paddy rice every year from 2000 to 2011. Damage to paddy rice caused by flood and drought is reported in the agricultural statistics of the Ministry of Agriculture, Forestry, and Fisheries (MAFF), especially from 1994. The compiled data of damage by drought and flood from various sources from 1984 to 2011 is shown in Figure 5.1. In total, drought damaged 1.09 million ha and flood caused twice that damage between 1984 and 2011. The figure is greater than the cultivated area in 2010, which was about 2.5 million ha.

It should be noted that Cambodia was experiencing civil war from the 1960s until the 1980s. Political stability has improved since 1993, when there was a general election supported by the United Nations Transition Authority in Cambodia. The data collected in this chapter is based on media reports, for example, articles from local newspapers, such as SPK, and the Agricultural Statistics Archive at the National Library and may not fully reflect the experience of Cambodian farmers at

[14] EM-DAT is an emergency event database and can be accessed online at http://www. emdat.be/database.

the time. However, the researchers have used multiple sources to ensure the data is as accurate as possible.

Flood and drought cause damage to paddy rice areas every year and are the most extreme climate events that occur in Cambodia (Ministry of Environment 2005b). Natural disasters had a considerable impact on Cambodia during the 2000s. The most severe flooding occurred in 2000–01 and 2001–02, when floods hit the farmers hard in two consecutive years. The impact of drought was worst in 2004–05. As shown in Figure 5.1, between 2000 and 2005, Cambodia was impacted by both flood and drought. Flood caused extreme damage to paddy rice again in 2011.

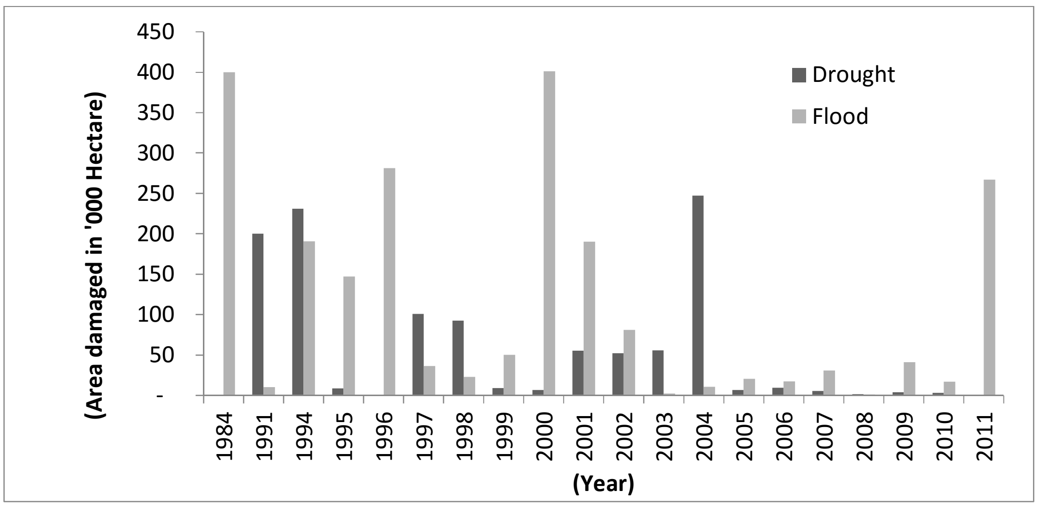
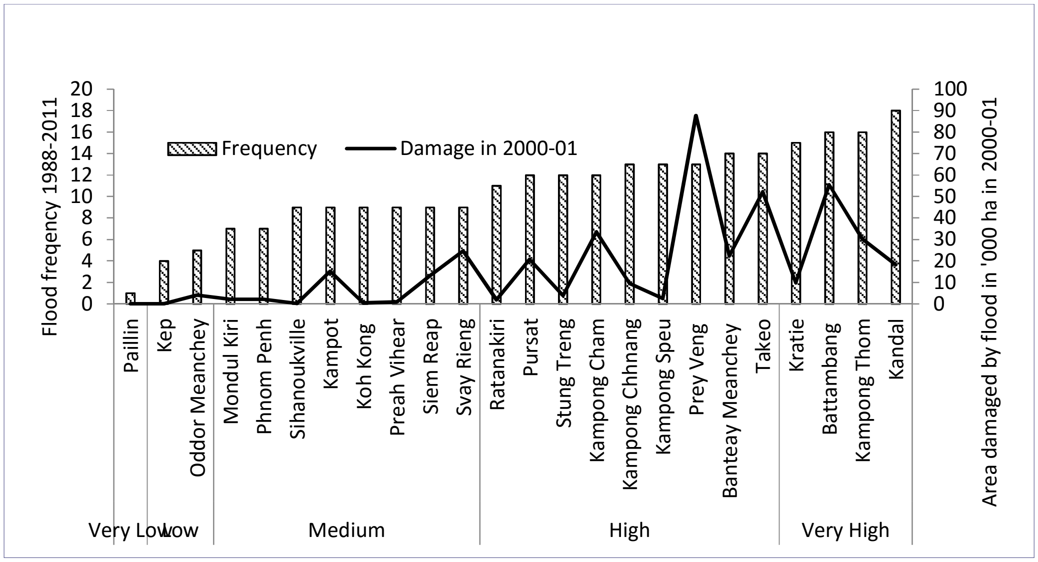


Figure 5.1: Flood and drought damage on paddy area in Cambodia, 1984–2011.

5.3.1. Flood

Figure 5.2 shows the frequency of flooding events by province in Cambodia. The frequency is based on data on flood damage to paddy rice from various sources such as agricultural statistics. Based on the frequency of flooding, the provinces most seriously affected between 1988 and 2011 were Kandal, Kampong Thom, Battambang and Kratie. Prey Veng, Battambang and Takeo are located either along the Mekong River (the Plain region) or in the Tonle Sap region, and they were badly impacted by flood in 1996, 2000, 2001, 2002 and 2011. It is generally agreed that in 2000 (or 2000–01 based on crop productivity records), flooding was the worst in 70 years. In 2000, Prey Veng paddy rice area was severely damaged compared with other provinces. It is estimated that about 100 people were killed and there was USD 170 million of agricultural losses due to flooding (Eng 2009).



Note: We categorised frequency as high, medium or low based on the number of years that a province was impacted by flood from 1988 to 2011: Very Low (1–2), Low (3–6), Medium (7–10), High (11–14) and Very High (15–18).

Figure 5.2: Flood frequency by province 1988–2011 and area damaged by flood in 2000–01 in Cambodia.

5.3.2. Drought

Figure 5.3 shows drought frequencies and associated damage to paddy rice area by province in Cambodia. Drought is recorded based on damage to areas of rice production caused by lack of water. There are three provinces that experienced drought very frequently, namely Kampong Speu, Takeo and Battambang. Prey Veng appears to be prone to both flood and drought, as the two worst disaster events in 2000–01 and 2004–05 badly damaged the paddy fields in that region. Based on annual drought information recorded by provinces in Cambodia between 1988 and 2011, the Kampong Speu, Takeo and Battambang provinces were considered the provinces most affected by drought[15].

[15] The annual drought recorded is based on a number of sources including national agricultural statistics, newspaper reports, Government disaster declarations, National Disaster Committee Management, Asian disaster Preparedness Centre and the Natural Disaster Database.

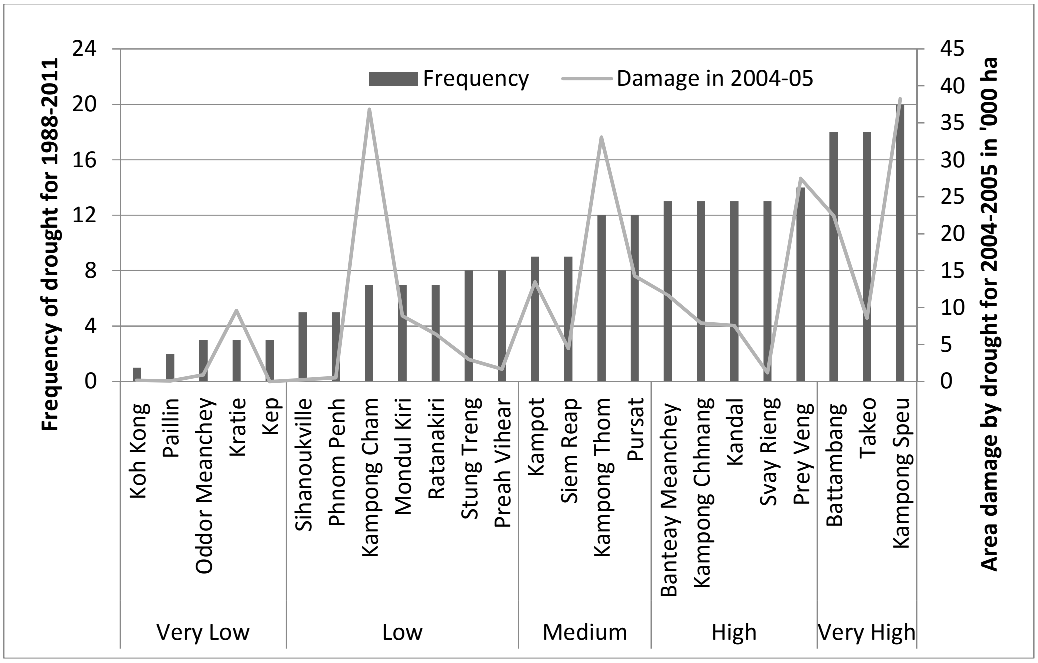


Figure 5.3: Drought frequency by province, 1988–2011 and area damaged by drought in 2004–05 in Cambodia.

5.4. Policy Response to Flood and Drought

The aim of policy response to climate change, especially in relation to flood and drought, is to address the challenges faced by farmers. The policy is designed to create an environment that increases farmer capacity and ensures effective input price with a reliable market price for paddy rice. The capacity of farmers will be promoted by agricultural extension services and providing access to credit that enables them to invest more in their paddy rice production. There should also be a crop insurance scheme to make sure that farmers have incentives to produce more rice.

Different government bodies approach flood and drought differently and with different action plans. For example, the main government authority responsible for natural disaster management is the National Committee for Disaster Management (NCDM), while the MoE is responsible for climate change resolution.

5.4.1. Institutional arrangements

There are two ministries that directly address flood and drought issues in the agricultural sector (mainly with regard to paddy rice): the MAFF and the Ministry of Water Resources and Meteorology (MoWRAM). The MoE and the NCDM are also involved with flood and drought issues but with different approaches.

The MAFF and its line authorities (the provincial departments and district agriculture offices) primarily deal with agricultural services including training, supplying seeds and technical and marketing research. The MoWRAM and its line authorities are primarily concerned with water resources, such as building physical infrastructure and supplying large–scale pumping machines as needed. For example, when there is drought the Department of Agriculture provides new seedlings for farmers and the Department of Water Resources sends large machines to pump water into paddy fields. Regarding flood, the MoWRAM is responsible for pre–intervention, such as early warnings, while the MAFF is responsible for post–intervention, for example, assisting with restoring rice fields after flood damage. The MoWRAM also has a role in establishing Farmer Water User Committees (FWUCs) to manage water in their respective irrigation projects. A FWUC is not a government authority but a group formed by local residents around the area where each irrigation scheme is located.

The MoE is taking the lead in planning with regard to climate change issues, however, it is worth noting that the MoE has no line authority to deal with flood or drought. It has produced the National Adaptation Programme of Action to Climate Change (NAPA). The NAPA contains 20 high priority projects (the most crucial and urgent projects for immediate funding), including nine that respond to drought and five to flood. Within their existing roles and responsibilities, the MAFF and the MoWRAM are the implementation bodies for the NAPA.

The government agency that deals with human security and Disaster Risk Reduction (DRR) is the NCDM. Within this agency, the line authorities (Provincial, district and Commune Committee Disaster Management) are responsible for early warning, evacuation and DRR Strategic Plan and Actions.

Although Cambodia appears to have distinct government agencies to address flood and drought, there is usually cooperation among relevant agencies. Intergovernmental agencies are also formed to accomplish specific tasks. For example, to investigate and deal with the effects of climate change, the government issued Sub–decree Number 35 in 2006 to establish the National Climate Change Committee, which has the prime minister as president, a minister from the MoE as chair and other high–ranking officials from relevant agencies as members. After the sub–decree was issued, working groups and task forces were formed as technical support to the National Committee.

5.4.2. Strategic plans and actions

The top–level development plan in Cambodia is the National Strategic Development Plan (NSDP). The NSDP's goal is to ensure that the country will achieve Cambodia's Millennium Development Goals[16]. The NSDP has 'good governance' as the central starting point, and it is hoped that achieving this aim will enhance development in the economy's major sectors, including agriculture. Discussion of the development involved in reaching the aim of good governance is beyond the scope of this chapter, however, it is central to the four components of the 'Rectangular Strategy', which includes (RGC 2010a, p. vi):

1. enhancement of agriculture sector;
2. further rehabilitation and construction of physical infrastructure;
3. private sector development and employment generation; and
4. capacity building and human resources development.

Using these national overarching development guidelines as a basis, individual government authorities develop their own strategic development plans and actions. For example, the MAFF released the Agricultural Sector Strategic Development Plan, 2006–2010. The document states the comprehensive actions to safeguard against flood and drought planned for by the MAFF, including:

1. water management and water supply;
2. land use planning and crop zoning;
3. soil fertility management and conservation; and
4. research and development in crops and marketing.

While the MAFF is primarily responsible for agriculture and the MoWRAM for water, the two bodies have produced a joint agriculture development strategy called the Strategy for Agriculture and Water 2006–2010. The document contains two main strategies to address flood and drought issues: improving water resources, irrigation and land management; and improving agricultural and water research, education and extension. The MoWRAM has also drafted the Climate Change Strategic Plan for Water Resources and Meteorology, 2013–2017. This plan provides road maps to adapt and mitigate the effects of climate change in Cambodia.

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[16] More information on the United Nations materials is available at http://www.un.org/.

There are a number of policies that, although not directly designed to deal with climate change adaptation, incorporate risk reduction strategies, such as the Strategic National Action Plan (SNAP) and the Law on Water. The SNAP, which is produced by the NCDM, addresses natural hazard risks including flood and drought. However, it mainly focuses on emergency arrangements and is not directly linked to climate change. The Law on Water of Cambodia deals with securing water for agricultural productivity and the welfare of people. Again, it has no direct association with climate change.

5.5. Flood and Drought Adaptation Practices

Flood and drought can be examined in relation to the paddy rice crop production period. Typically, a one–year crop calendar covers an 11–month period that crosses two standard calendar years (Figure 5.4). For example, in 2013 the wet season rice grows from May to November 2013 and dry season rice from December 2013 to April 2014. Flood and drought occur only during the growth of wet season rice. Flooding usually occurs in September and drought may occur within any of the three rice–growing periods, during planting of seedlings, transplanting and harvesting.

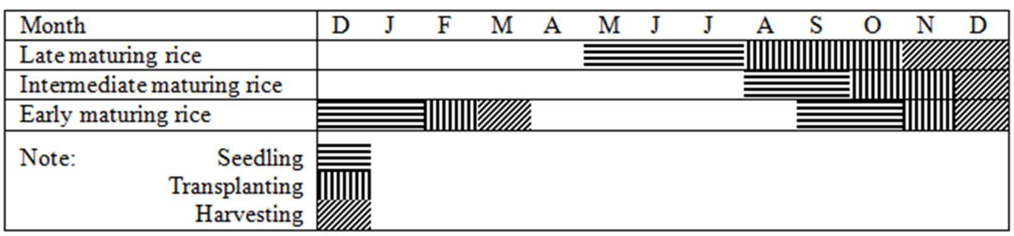

Figure 5.4: General paddy rice crop calendar in Cambodia.

5.5.1 Adaptation to flood

The provinces that are in the two river catchments (the Mekong and Tonle Sap Rivers) are highly prone to the combination of flash flood and annual river flood[17]. From 1991 to 2011, half of all flash floods occurred within the second and third week of August and in September, which is during the period when rice plants are vulnerable. Flash flooding causes the rice plants to become weak and the annual flood intensifies and prolongs the flooding period. There are two rice ecosystems within the plain area that are known by local people as *sreleu* (which is grown at higher latitude) and

[17] 'Flash flood' refers to flooding within a short period caused by torrential rain in mountainous and highland areas that floods the plains. 'Annual river flood' is a seasonal flood caused by overflow of water in the river, especially the Tonle Sap and Mekong River.

srekrom (deep–water rice). The cultivation in the former area is rain–fed and the latter uses the hydrology of lakes and rivers (Javier 1997). Currently, farmers adjust the crop calendar to escape from drought and flood. For example, to avoid flash floods, farmers in rain–fed areas start their cultivation in May and harvest in August, but they may then be faced with drought. In deep–water rice cultivation, farmers cultivate before the arrival of flood waters as the plant will not grow much as the water rises. However, the rice yield is very low, with as little as 500 kg per hectare (Mak 2011).

Like drought, flash flooding can occur at any stage of the paddy growing period, but it is most destructive for plant yield if it occurs during the transplanting period (see Figure 5.4). At early growth stages, the plant needs to be submerged in the field for long periods and is vulnerable to the fast–flowing surface run–off that accompanies flooding.

A study conducted by the Ministry of Environment (2001) suggests the options for agriculture to respond and adapt to climate change are the use of high–yield crop varieties, implementing early warning systems, improved irrigation, mapping flood and drought–prone localities, crop management, cultural practices and food diversification. These options were outlined in Cambodia's Initial National Communication to the United Nations Framework Convention on Climate Change in 2001 (Ministry of Environment 2002). Early warning systems have been introduced at the local community level to monitor floods. However, they are mainly used for evacuation.

One promising area of adaptation to flooding is to use methods that result in high yields during flood and drought conditions. These are being tested by a number of scientists and have proved successful so far, but are still in the development and testing stage (Ministry of Environment & UNDP 2011; Ikeda *et al.* 2008). Ikeda *et al.* (2008) indicate that using direct seedlings (seedlings that do not require tillage or transplanting) in different water conditions might lead to higher yields at a lower cost (as the farmer uses less labour to prepare the seedlings).

5.5.2. Adaptation to drought

Based on current practices of paddy rice production (as shown in Figure 5.4), adaptation to drought must take into account three different types of drought, namely early–season drought, mid–season drought and late–season drought, which occur in June–July, August–September and October–November, respectively. There are two options widely discussed in the literature, namely changing seed varieties and building irrigation systems.

Changing seed varieties to adapt to drought

When farmers use late–maturing varieties of rice, it takes six months from planting seedlings to harvesting. For these farmers, the delayed onset of rainfall (May–July) is a drought event referred to as early–season drought. When such drought occurs, they may or may not change the seed varieties to intermediate–maturing varieties. The majority of farmers prefer late–maturing varieties, which are their traditional varieties of rice. By planting them the farmers take a risk. However, some farmers may wait until they have enough water in the rice field and use intermediate–maturing varieties. Such farmers must have two seed varieties to enjoy the flexibility of choosing between late– and intermediate–maturing varieties.

Cambodia normally experiences a period without rainfall for two weeks in early August. If this period stretches longer than two weeks, farmers who used late– and intermediate–maturing varieties experience drought that is called mid–season drought. If their paddy is damaged, the only option remaining for farmers is to use early–maturing varieties, but they are preferred least by farmers. Finally, there is late–season drought, which occurs when there is early cessation of rainfall (November and December) and affects all varieties of rice.

Water management

Drought can affect farmers regardless of which rice seed varieties they cultivate. Therefore, water management, such as building water reservoirs, must be considered. Farmers with access to water from irrigation schemes perform better than those lacking access, irrespective of whether or not there is drought. This is the most desirable option to mitigate the adverse effects of drought.

The RGC is promoting drought–resistant varieties of rice in addition to rehabilitating and constructing physical infrastructure, meaning that farmers can select which variety of rice to plant depending on the rainfall in a particular year[18]. Tsubo *et al.* (2009) find that when seeds are transplanted in June, farmers should select intermediate–maturity varieties so that the plant can avoid drought during the growing period and if sown in August, farmers should use early–maturing varieties.

[18] Ten rice varieties promoted by the RGC from 2011 are: (i) Sen Pidao, (ii) Chul'sa, (iii) IR66 (these are early maturity), (iv) Phka Rumdoul, (v) Khka Romeat, (vi) Phha Romdeng, (vi) Phka Chan Sen Sar (these are intermediate maturity), (viii) Riang Chey, (ix) CAR4 and (x) CAR6 (these are late–maturity).

In the case of rain–fed rice production, good rainfall during May and June induces farmers to practice their normal paddy rice cultivation. However, if this is followed by a dry spell of longer than two weeks in August, rice production is greatly impacted. As a first response to drought, farmers pump water from nearby sources such as ponds or tube wells. Without access to water, rice plants gradually wither and die and farmers must replant. However, poor, small landholder farmers usually have no seed remaining after the first planting. Currently, if this type of drought occurs and there is water nearby, government agencies take the steps necessary to save the rice plants by supplying small– and large–scale water pumps so that water can be transported to the rice fields. With the remaining destroyed rice fields, farmers can either wait for the appropriate conditions to plant early–maturity rice varieties or leave rice fields uncultivated.

The most severe drought condition occurs when rainfall ceases during the grain–filling period (October to November) or the harvesting period. In this situation, the only possible plant–saving strategy is pumping water from water sources near the rice fields, but this becomes difficult or impossible when the drought is long and the nearby water bodies are unable to supply enough water.

The Ministry of Agriculture, Forestry, and Fisheries (2011) and Sovacool *et al.* (2012) state that adaptation to flood and drought should come in three forms: changing seed varieties to those resistant to drought and flood; showing farmers how to use new farming methods, including integrated farming systems and the system of rice intensification (SRI); and providing training on how to build institutional, technical and capital resilience for climate–proof irrigation. Institutional resilience includes building the capacity of villagers to cope with drought and flood, and local authorities participating in the implementation of NAPA projects.

5.6 Adaptation Discussion

There are at least two main challenges in agricultural production in Cambodia. First, natural hazards are more intense and occur more often. The Ministry of Environment (2001) and IPCC (2007) agree that current trends will continue and climate change will affect rainfall distribution both spatially and temporally. The negative impacts of climate change will continue to occur. Second, agricultural development in Cambodia is relatively slow. Historically, Slocomb (2010) argues that Cambodia has failed to develop its agricultural sector. Overall, while the government and farmers are trying to address the challenges, flood and drought are still occurring and affecting agricultural development.

It is believed that securing water for rice production is the most necessary and vital action for Cambodia to take to address the effects of climate change, followed by the other options listed in Section 5.5. While the crop varieties and crop calendar approach can be combined, without water no option is effective. At the same time, farming techniques such as SRI that can cope with paddy soil fertility and climatic conditions must be provided by scientific research. According to the Ministry of Agriculture, Forestry, and Fisheries (2006), the constraints on rice production in Cambodia include an inadequate irrigation infrastructure, lack of agricultural inputs to improve soil fertility, limited access to education, training, credit and research, among many other enabling factors.

Despite existing work in agricultural development, paddy rice production has been affected by adverse climatic conditions. Perhaps it is time to revisit existing work and practices and examine how they could be altered to deal with the challenges of climate change. Given the openness of terrain in the flood plains of the two river systems, investment in infrastructure, such as dikes, may be costly. However, the government is implementing some initiatives to address this issue, as indicated in the NAPA.

It has been suggested that adaptation to climate change is no different from adapting to current climate hazards and that increasing resilience to climate hazards and reducing poverty are the key to increasing climate resilience in developing countries (Johnston *et al.* 2010). For Cambodia, adapting to floods means using flood–tolerant varieties of rice and, where possible, building dikes to prevent flooding. However, although these practices have been implemented, flood still damages rice production, as it did in 2011 when it destroyed crops on more than 10 percent of Cambodia's total paddy area.

In short, many studies indicate that changing crop varieties and water management are the most common adaptive strategies being practised by households in Cambodia, in that early–maturing rice varieties are being used and rice plants are now established after floods have receded (Ministry of Environment & UNDP 2011; Ros *et al.* 2011; Ouk *et al.* 2007). Since holding water in the rice fields is very critical for paddy rice, a common practice is for farms to raise their farm dike to hold water until the plants are ready to be harvested (ADPC 2005). However, an empirical study by Geres–Cambodia (2009) finds that changing crop calendars could also cause crop damage due to lack of

rainfall towards the end of the rainy season and even households who use flood–resistant rice varieties are affected by drought.

5.7. Conclusion

Evidence of climate change effects in Cambodia is real and climate change models have predicted that effects will continue to worsen. In this chapter, there have been demonstrated that agricultural production has been impacted by flood and drought. Between 1984 and 2011, on a national scale flood and drought were considered Cambodia's most severe natural disasters. The flooding in 2000 was the most severe in four decades and was repeated with similar intensity in 2001. In 2002, the country experienced both flood and drought.

The NAPA is a national adaptation action plan with minimal geographical coverage, which clearly defines Cambodia's planned adaptation activities, along with the specific location and budget estimate of each project proposed. In terms of institutional arrangements, the executive authority for managing water in Cambodia, appointed by the RGC, is the MoWRAM, which works in conjunction with a number of organisations from the government, civil society and the private sector. Where there are irrigation schemes at the community level, FWUGs are formed with technical support from the MoWRAM to ensure that water is used productively, wisely and in an equitable manner.

Adaptation activities include, but are not limited to, building dike and irrigation systems, which are recommended by almost every study on Cambodia's climate adaptability. Other recommendations advocated for adaptation include stronger agricultural extension services and changing inputs and crop varieties.

Structural adaptation measures proposed and implemented in Cambodia are focused on water management strategies to protect the country against drought and flood induced by climate change. These measures involve changing from rain–fed to irrigated agricultural practices. Although the NAPA is designed to be an adaptation action plan driven by climate change, it is effectively the same as other adaptation plans proposed in the literature about Cambodia related to adapting to drought. Research and development is needed to develop adaptation measures that can respond to climate variability, extremes and changes in long–term conditions affected by climate change.

In conclusion, the process of adapting to climate change in Cambodia is currently in an early stage. Agricultural production is still highly sensitive to changing rainfall and shifts in the duration and occurrence of rainfall have resulted in damage to production. This is closely associated with the low adaptive capacity of farmers due to their environmental, social and economic status. While experiencing the effects of climate change, farmers are also faced with high costs of inputs and an unstable price of output. This overall adaptive weakness requires improvement in government intervention, which is still at an early stage in terms of geographic coverage and practical options. From a government perspective, more should be done to ensure that farmers are able to cope with drought and flood including agricultural extension services, providing credit at low interest to farmers, enlarging the coverage of irrigation schemes, minimising the cost of inputs and optimizing the outputs of farmers. If these conditions are met, farmers will have the environmental, social and economic capacity to cope with flood and drought.

Acknowledgements

This work was carried out with the aid of a grant from the International Development Research Centre (IDRC) in Ottawa, Canada and the Economy and Environmental Program for Southeast Asia (EEPSEA). The following people contributed to gathering data for this project: Cheb Hoeurn, Kong Sopheak, Sen Rineth, Noan Sereyroth and Cheang Sokhy. The comments and editing from Professor Sushil Vachani of Boston University are highly appreciated.

CHAPTER 6: SUMMARY AND RECOMMENDATIONS

6.1. Introduction

Droughts are major and recurrent natural disasters in Cambodia despite the rainfall being approximately 1,200 millimetres per annum. Buckley *et al.* (2010) suggest that Cambodia has experienced ongoing interdecadal droughts in the past and that this may have even contributed to the demise of the Angkor civilisation. Through research such as that accomplished in this thesis, past Cambodian droughts should be considered lessons from which all stakeholders in the country can learn and prepare for future drought risk as posited by IPCC (2014). This focus is critical given the fact that IPCC has projected that in the near term (as well as over longer time scales) the risk of drought-related disasters in Asia medium to high (2014, p. 1336). Droughts lead to damage to rice production and crop losses, such as in 2004 when some 12 percent of the cultivated area was destroyed. However, even the severe 2004 drought varied in severity between provinces, as described in Chapter 5.

This thesis sought to: (i) quantify drought severity by selecting a drought prone province in Cambodia to examine, based on the Standardized Precipitation Index (SPI), (ii) compute the costs of drought within a period of time using risk based analysis, and (iii) discuss how drought should be managed in Cambodia.

The major findings of the thesis are summarised in the next section. These will be followed by recommendations on how drought could be managed proactively in Cambodia.

6.2. Major Findings

Chapter 3 provides an examination of the influence of regional climate (especially the El Niño Southern Oscillation) on precipitation variability in Kampong Speu province (using the SPI), and links SPI with drought damage to rice production. Chapter 4 investigates drought impacts on socio-economics at the household level by comparing farmers who utilise rain–fed irrigation to those using supplementary irrigation. Chapter 5 examines drought in the broader aspects of drought debated in the risk literature (as elaborated in Chapter 2).

6.2.1. Drought and rice production in Kampong Speu

The main aim of Chapter 3 is to address the questions of whether it is possible to determine drought onset, understand drought severity, and realise the cessation of drought events in Cambodia.

Cambodia's climate is strongly influenced by the Tibet plateau, Indian Ocean, and El Niño Southern Oscillation (ENSO). The twelve–month SPI in the growing season (May–November) is significantly correlated (*CR = 0.455, p= 0.00*) with three–month–time–lagged Niño 3.4. The probable climate mechanisms that can be used to explain this are that:

1. weak monsoons and El Niño are strongly correlated (Stott *et al.* 2002);
2. because of its situation on the Indochina peninsula, Cambodia is influenced by three major monsoon sub–systems, namely the Indian Summer Monsoon (ISM), East Asian Summer Monsoon (EASM), and Western North Pacific Summer Monsoon (WNPSM); and can be described as a complex buffer zone between these sub–systems (Wang & Lin 2002);
3. the climatic condition in the buffer zone is strongly influenced by ENSO (Chen & Yoon 2000);
4. early onset of the wet season in Indochina is associated with early cessation (Misra & DiNapoli 2013); thereby enhancing the severity of droughts; and
5. levels of ENSO activity take from one to three months to manifest their impacts in western Pacific countries (Su *et al.* 2005).

Therefore, Niño 3.4 could be used in conjunction with SPI to develop an early warning system for meteorological drought in Cambodia. However, drought early warning should not be just based on climate data but also on factors like the cropping calendar and rice varieties.

The seasonal and annual variations in rainfall in Kampong Speu (KPS) that lead to drought in the area can be described as follows: (i) late onset, (ii) prolonged dry spells during mid–season and (iii) early cessation. However, even a severe drought (low SPI values) does not always translate into severe paddy damage (Chapters 3 and 4). Good rainfall in the early growing season triggers farmers to cultivate long maturing varieties (which is their preferred traditional practice, as they provide greater yields and the grain fetches a good price on both local and international markets). Farmers may also have local knowledge that early onset rainfall will be accompanied by late cessation rainfall. However, by cultivating long maturing rice, farmers may face the risk of mid–season dry spells in August.

From Chapter 3, it is clear that there were some years when rain did not fall in the early growing season, but that this did not result in significant paddy damage. In this case it is likely that farmers did not start cultivating early but waited for the second rainfall peak which usually occurring late August or early September. In these years, farmers will have prepared medium maturing varieties to plant in August and to be harvested in late November. This is supported by the observation in Chapter 4 that farmers managed risk by keeping medium varieties as their second best option in the event of a late onset of the monsoon.

When farmers do cultivate medium maturing varieties in September during the later peak in rainfall, the main risk then becomes early cessation of rainfall. Early cessation of rainfall impacts on all varieties of wet season rice (long, medium and short) and therefore this risk has the potential to strongly affect household food security and Cambodia's total rice production (94 percent of rice production is wet season (Ouk 2013).

Continued reliance on rice growing using rain–fed irrigation is likely to become increasing risky in the coming decades, especially in the context of global warming. As discussed in Chapter 5, climate change models predict that rainfall patterns will shift. If these predictions are correct, wet seasons will become shorter and the distribution of rainfall in the growing period (May–July[19], August–September[20], and October–November[21]) will change. The Ministry of Environment (2001) predicts that there will be less rainfall during the early growing season and more in the late season under future climate change scenarios. This suggests great reliance will need to be placed on only medium and short maturing rice varieties in the future. However, the practice of using long maturing varieties may still be viable under certain supplementary irrigation conditions.

6.2.2. Economic costs of drought

Chapter 4 examines how meteorological drought leads to tangible impacts on paddy production, in particular it provides more details on how interseasonal variability of rainfall contributes to drought and what measures could be used to mitigate drought impacts.

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[19] Suitable for long maturing varieties.

[20] Suitable for medium maturing varieties and short varieties.

[21] The period when any variety will be suitable.

Drought impacts on an array of economic, social and environmental elements. For paddy rice, the impacts are not just related to the area damaged by drought but also the many hidden costs. Chapter 4 reported three categories of hidden costs including (i) the interruption cost due to the intensification of labour and inputs, (ii) yield reduction, and (iii) loss of harvested area – as the size of area harvested is smaller than the area cultivated. For example, early season drought may destroy paddy seedlings. The data relating to this kind of pre–harvest damage are not recorded in national statistics. There are also additional costs related to water pumping, weed and/or pest control during abnormally dry periods. Some farmers reported that they cultivated three times in one particular droughty cropping season but failed two times and only successfully cultivated paddy in the late wet season though yields were low. Again, the costs of the first two failed harvests are typically not recorded in official statistics.

Chapter 4 also reported on (i) annual expected costs (AEC) for farmers relying on rain–fed cultivation, (ii) AEC for farmers cultivating with supplementary irrigation, and (iii) risk–based cost and benefits (CBA) of a dike if rehabilitated in a rain–fed cultivation area. Per hectare, farmers using rain–fed cultivation face AEC of approximately USD 54.00 per annum while for farmers with supplementary irrigation AEC are less at USD 23.00 per annum. The risk based cost–benefit analysis shows that the investment in dikes (or other forms of harvesting runoff) will not only secure water for farmers, but also provide livelihood diversification. This is in turn will help ensure food security and contribute to poverty reduction.

The underlying message from Chapter 4 is that farmers who depend on rain–fed rice cultivation will be impacted the most from drought. The anticipated losses due to drought in rain–fed paddy cultivation are twice that of supplementary irrigated paddy cultivation systems. An important and related issue is that farmers cultivating rain–fed fields were reluctant to invest further in rice production. Specially, they were not prepared to be exposed to the financial risks involved in fertiliser applications as drought can occur at any time between transplanting and harvest. In contrast, farmers using supplementary irrigation were willing to invest more on rice production (e.g., especially in fertilisers use and infrastructure development) and as a result, their yields were more than two or three times those of rain–fed farmers.

6.2.3. Drought response in Cambodia

Chapter 5 highlights a number of important findings and provides background to the following section on recommendations. The major contribution of Chapter 5 is an understanding of how drought could be managed by various stakeholders in the light of the constraints faced by farmers and government agencies. These constraints are (i) the fact that farmers generally have a low adaptive capacity in areas such as involvement in new farming techniques; e.g. Systematic Rice Intensification (SRI), and this leads to continued low yields. (ii) the costs of inputs to rice production systems, e.g., fertilisers, pesticides, and fuel, are relatively high and most farmers cannot afford them, (iii) unstable rice markets are a further factor that leads to an uncertain economic framework for most rice farmers. In particular these affected farmers who accumulate debts during the growing season are expected to pay them after harvest, (iv) only about eight percent of agricultural production in Cambodia has access to irrigation, which exposes the majority of farmers to a high risk from climate variability.

Chapter 5 also illustrates how, in Cambodia, all stakeholders related to drought management are currently responding reactively. To be proactive in drought management, Wilhite *et al.* (2014) suggest that the overall framework of drought risk management should be within the recovery cycle (including impact assessment, response, recovery and reconstruction) and protection (including mitigation, planning, monitoring and prediction). Furthermore, UNISDR (2009) suggested that drought early warning systems are a core part of societal resilience to drought. For Cambodian farmers, the challenge is that because they have a low adaptive capacity, it is extremely difficult to take any proactive measure to prevent and/or reduce drought impacts. Aside from climate variability, the risks faced by farmers also stem from their unsafe condition (living in a drought prone area), through dynamic pressures (having weak social capital), to root causes (unstable rice market and high input costs). All of these conditions exacerbate farmers' vulnerability. These factors are compounded by the lack of adequate drought assessments in Cambodia as well the absence of any drought early warning mechanisms.

6.3. Recommendations for Drought Management in Cambodia

A drought risk management framework, as proposed by UNISDR (2009), is summarised as shown in Figure 6.1 and includes drought preparedness (drought prevention measures), drought vulnerability reduction (vulnerability reduction measures), and drought recovery actions (drought reduction

measures). Wilhite *et al.* (2014, p. 9) have suggested a 10–step process required to make the framework operational:

1. appoint a drought task force or committee;
2. state the purpose and objectives of the drought mitigation plan;
3. seek stakeholder input and resolve conflicts;
4. make inventory of resources and identify groups at risk;
5. prepare and write the drought mitigation plan;
6. identify research needs and fill institutional gaps;
7. integrate science and policy;
8. publicise the drought mitigation plan to build awareness and consensus;
9. develop education programs; and
10. evaluate and revise drought mitigation plans.

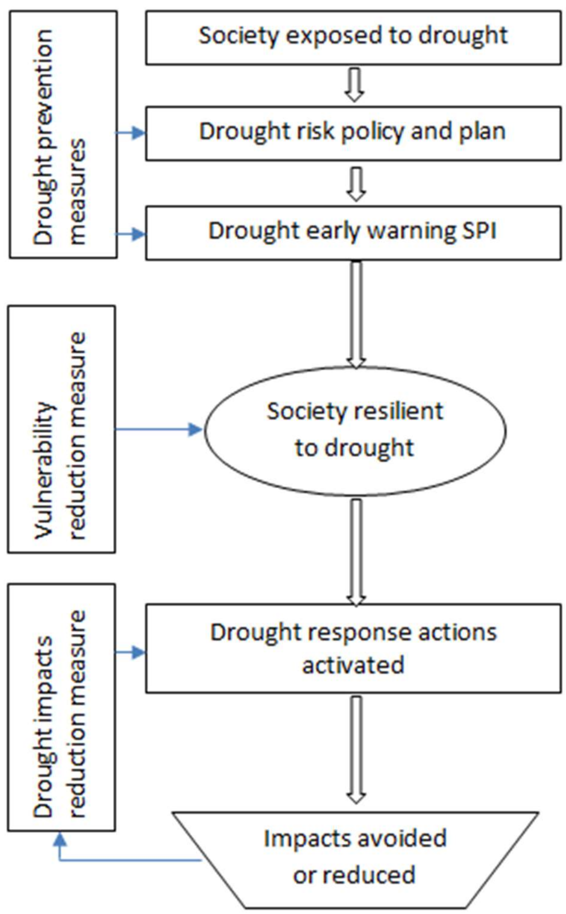

Figure 6.1: Drought risk management framework.

Source: Modified from UNISDR (2009) and Wilhite (2005).

As discussed throughout this thesis, drought mitigation requires government intervention. Drought alleviation is a priority in the National Strategic Development Plan (NSDP) (Royal Government of Cambodia 2014; 2010a). However, the NSDP is a road map for Cambodian development as a whole, and the plan provides policy direction to different authorities and Ministries to address drought impacts as related to their portfolios. Those ministries dealing directly with drought, as listed in the Strategic National Action Plan (SNAP) for Disaster Risk Reduction 2008–2013, are the Ministry of Agriculture, Forestry, and Fisheries (MAFF), the Ministry of Water Resources and Meteorology (MoWRAM), the Ministry of Environment (MoE), and the Ministry of Rural Development. However, the National Committee for Disaster Management (NCDM) is the main authority responsible for managing drought risk, as well as other hazards across the country. The roles and responsibilities of each ministry and authority related to droughts and floods have been elaborated in Chapter 5.

There is no separate body (or task force) to address drought in Cambodia as proposed by Wilhite *et al.* (2014). Based on current roles and responsibilities, the NCDM should become the leading authority in drought mitigation at all levels (national to local). This is because one of the roles and responsibilities of the NCDM is that the NCDM general secretariat 'makes recommendations to NCDM regarding the declaration of an emergency in a devastated area at the national level as well as the declaration of an emergency by governors at provincial/municipal levels'. But currently this is not explicit with regard to drought. It is also apparent that the rest of the steps proposed by Wilhite *et al.* (2014) are absent in Cambodia. The NSPD indicates that the NCDM will:

1. strengthen disaster management institutions from national to local levels;
2. enhance disaster risk assessment and monitoring and improve early warning systems, though this is only stated for floods;
3. innovate and develop new knowledge, and provide training to build a culture of disaster resilience;
4. reduce risk factors; and
5. strengthen preparedness for effective emergency response from national to local levels, though drought is not explicitly mentioned.

If the 10–step procedure is to be followed, the national task force should at least comprise representatives from NCDM, MAFF, MoWRAM, MoE, and MRD. The following step is that there

should be a national drought risk policy and plan. The current Strategic National Action (SNAP) for Disaster Risk Reduction (DRR) for 2008–2013 is out of date and anyway it only specifies overarching actions for all natural hazards. There is no specific task described in SNAP which requires the establishment of drought early warning systems, nor anything specific to other natural hazards.

The exercise of producing a SNAP is very similar to steps 4–7 (Wilhite *et al.* 2014) but it needs to be specific to drought. For example, identifying groups at risk in relation to multiple hazards would be misleading if just drought was being addressed. It is very important to integrate different authorities, scientific findings and policy prescriptions on drought mitigation. For example, currently the MoE could mobilise resources to address drought (based on climate change studies) through a climate change adaptation fund and furthermore they could propose a project without consulting with other ministries like MAFF. The potential conflicts of the failure to integrate in this example would be that while the MoE is trying to address potential drought impacts created by global warning at a particular location in the future, the current factors that underpin drought vulnerability would not be being addressed.

Publicising a drought mitigation plan step (step 8) (Wilhite *et al.* 2014) is another key as it allows other stakeholders to align their policies and action plans accordingly. For example, there are a number of private sector and Non–Governmental Organisations who are working to address drought issues in Cambodia. Developing educational programs on drought mitigation measures (step 9) is critical: for instance, they could integrate training on how farmers can use early warning information and tailor their cultivation practises. Finally, the drought mitigation plan should be evaluated and revised by external and/or internal experts based on the changing vulnerability factors (as indicated in step 10). These repeating cycles of the drought management framework, therefore, will put drought disasters in check.

6.4. Limitations and Recommendations for Further Investigation

This thesis did not address why Kampong Speu (KPS) is particularly drought prone compared with other provinces in Cambodia and therefore it is possible that SPI may not be suitable for use in other provinces or that the drought thresholds (Section 3.5) may need to be adjusted with locations as these are likely to be dependent on other environmental parameters e.g., soil moisture. Drought impacts may be driven by levels of socio–economic development locally.

Detecting early or late cessation of rainfall using regional climate indices (such as those related to ENSO) looks promising in providing basic early warning systems. In this study, only Niño 3.4 was significantly correlated with SPI. Other Niño Indices or other climate indices that related to ENSO need to be evaluated for other provinces.

A critical line of investigation for further research is on rainfall distribution and drought impacts per growing period. In particular, how much does early, mid, and late wet season rainfall contribute to good yields and lower production costs?

A mechanism to cross check the outputs of drought monitoring with those from the World Meteorology Organization (WMO) and neighbouring countries needs to be developed to ensure consistency and accuracy. There are drought monitoring systems in other parts of Southeast Asia (Thenkabail *et al.* 2004) which can be used to cross check with Cambodia, and broader characteristics of monsoon systems may also provide useful information.

While harvesting runoff water is an option to supplement irrigation in many rain–fed systems (as examined in this study), there should be investigations on ground water harvesting. Farmers can invest a small amount of money in making a well to secure water for supplementary irrigation, and this may be more economically feasible than building dikes and water storages.

6.5. Conclusion

This thesis argues that rain–fed paddy rice cultivation in Kampong Speu Province in particular, and Cambodia more generally, is at high risk from high–frequency recurrent drought impacts. The risk in agriculture is from both climatic and socio–economic aspects. Three approaches to manage drought risk are suggested.

1. SPI should be used to monitor rainfall and be incorporated in drought early warning systems in Cambodia.
2. Paddy rice production should have increased access to supplementary irrigation via small scale storage.
3. Comprehensive drought risk management programs as proposed by UNISDR need to be established urgently in Cambodia under the leadership and management of the NCDM.

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