Development and Climate Change in the Mekong Region

Case Studies

edited by

Chayanis Krittasudthacheewa

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Abbreviations

ADB	Asian Development Bank
APN	Asia-Pacific Network for Global Change Research
CORDEX	Coordinated Regional Downscaling Experiment
DAFO	District Agriculture and Forestry Office
DFID	Department for International Development
DMH	Department of Meteorology and Hydrology
DNP	Department of National Parks and Wildlife Conservation
DONRE	Department of Natural Resources and Environment
DRR	disaster risk reduction
DWR	Department of Water Resources
EWEC	East-West Economic Corridor
FA	Forestry Administration
FCPF	Forest Carbon Partnership Facility
FD	Forest Department
FGD	focus group discussion
FiA	Fisheries Administration
FPCP	Forest Carbon Partnership Facility
FPIC	Free, Prior and Informed Consent
FREL	forest reference emission level
FRL	forest reference level
GHG	greenhouse gas
GIS	Geographic Information System
GMS	Greater Mekong Sub-Region
GoL	Government of Lao PDR
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resource Management
ITTO	International Tropical Timber Organization
KPWS	Kulen Promtep Wildlife Sanctuary
LMPPI	Lower Mekong Public Policy Initiative
MAFF	Ministry of Agriculture, Forestry and Fisheries
MDG	Millennium Development Goals

MoE	Ministry of Environment
MOECAF	Ministry of Environmental Conservation and Forestry
MONRE	Ministry of Natural Resources and Environment
MOWRAM	Ministry of Water Resource and Meteorology
M-POWER	Mekong Program on Water, Environment and Resilience
MRC	Mekong River Commission
MSSRC	Mekong Sub-region Social Research Center
NAPA	National Adaptation Programme of Action
NFMS	National Forest Monitoring System
NGO	Nongovernmental Organization
NKS	Nong Kae Sub-district
NRS	National REDD+ strategy
NSPWRM	National Strategic Plan on Water Resources Management
NTFP	non-timber forest product
OCHA	Office for the Coordination of Humanitarian Affairs
PAFO	Provincial Agriculture and Forestry Office
PRA	participatory rural assessment
RBP	results-based payments
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RCRD	Research Centre for Rural Development
RDS	Robust Decision Support
REDD+	Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
RFD	Royal Forest Department
RID	Royal Irrigation Department
R-PP	Readiness Preparation Plan
RS	rice straw
SEA-START	Southeast Asia SysTem for Analysis, Research and Training
Sida	Swedish International Development Cooperation Agency
SIS	Safeguard Information System
SLA	Sustainable Livelihoods Approach
SUMERNET	Sustainable Mekong Research Network
SWAT	Soil Water Assessment Tool
SWMM	Storm Water Management Model
TEEB	The Economics of Ecosystems and Biodiversity

UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
USAID	United States Agency for International Development
US-EPA	United States Environmental Protection Agency
VMD	Vietnamese Mekong Delta
WEAP	Water Evaluation and Planning
WRM	Water Resource Management
YDNP	Yok Don National Park

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Preface

Building a research network with partners in many countries is not an easy task. Even more difficult is to not only keep it going for 15 years but also producing a wide range of knowledge and making it accessible at different levels in various media. This is the singular achievement of the Sustainable Mekong Research Network (SUMERNET), a research and policy engagement network in the Mekong Region that was launched in 2005. Since then, after the first two phases—Phase 1 (2005–09) and Phase 2 (2010–13)—SUMERNET has now expanded to involve more than 100 researchers and 50 affiliated institutions across the region in its just concluded Phase 3 (2014–18).

Even as the Mekong Region has undergone transformation in recent years, SUMERNET partners have also kept pace with the changes in the region. SUMERNET partners lead interdisciplinary, cross-national studies on major policy issues; engage with policymakers, planners and stakeholders; and build capacity among both researchers and policymakers. We have sought to understand environmental issues and changes with research for policy solutions, and continually produced high-quality knowledge products.

These knowledge products range from the SUMERNET book series to reports, working papers, and policy briefings, as well as blogs and news. More recently, SUMERNET has also taken advantage of the growing digital advances and social media to highlight the regional challenges and alternatives through a multimedia series of documentary films and photo stories.

The countries of the Mekong Region have mostly continued in their path of rapid economic growth and increasing regional economic integration. However, poverty and social inequality—including gender inequality—remain significant challenges in the region.

Sustainability is a major concern, as environmental degradation takes a toll on both ecosystems and livelihoods, and competition over limited natural resources becomes increasingly common, often cutting across national boundaries. Combined with these existing challenges is the serious concern of climate change that is causing severe negative impacts on many food-producing areas of the Mekong Region, posing risks of food insecurity. Droughts and floods occur with more frequency and intensity. At the end of 2015 and early 2016, for instance, the entire region experienced one of its worst recorded droughts in recent decades. The effects of this drought, and subsequent salinity intrusion, are still being felt in many areas such as the Mekong Delta in Vietnam.

This edited volume *Development and Climate Change in the Mekong Region: Case Studies* is the second volume in the SUMERNET book series. The work for this volume emerged from SUMERNET's ten collaborative research projects to address various sustainable development issues under four themes: • Ecosystem services, resource use and impacts • Transboundary issues • Energy & climate change • Poverty and livelihoods. The chapters in this volume provide an in-depth look at some of the key environmental and climate change issues faced by the Mekong Region and evaluate key findings and their implications for improved policies, based on the close engagement of the project teams with local and national policymakers and other partners.

This volume highlights the range and intensity of these environmental challenges as well as provides recommendations for local, national and regional policymakers, donors and other actors involved in supporting sustainable development in the Mekong Region.

The fruit of this collaborative research work and engagement with policymakers and other stakeholders by the SUMERNET partners form the basis of this book. This book therefore would not have been possible without the research activities and policy partnerships across the countries undertaken by SUMERNET researchers, both in and outside the Mekong Region. Such successful collaborations will be continued and strengthened in the next Phase of SUMERNET 4 All, which will focus on a key challenge in the region: water insecurity.

We trust that this SUMERNET volume will prove useful for researchers, policymakers, and other readers seeking to understand and work towards the sustainable development of the Mekong Region.

Chu Thai Hoanh
Chair, SUMERNET Steering Committee
June 2019

1

Introduction: Addressing development and climate challenges in the Mekong Region

Chayanis Krittasudthacheewa, Hap Navy, Bui Duc Tinh and Saykham Voladet

Even as the Mekong Region continues to undergo rapid socioeconomic development and regional integration along with a liberalized market economy, it is facing ever more intense ecological degradation and damage to its natural ecosystems. Poverty and social inequality—including gender inequality—remain pressing concerns. In recent decades, moreover, the impacts of climate variability and change have become more evident as the region struggles with intense droughts and floods, and changes in rainfall and temperature patterns, which are taking a toll on both rural and urban areas (Lebel et al. 2014).

National governments largely continue to focus on the exploitation of natural resources for shorter-term economic gains. The importance of environmental sustainability, social inclusiveness and gender-responsive policy and practice still needs to be advocated more among policymakers, business, and the wider public. The vision of sustainable development that was talked about in the 1980s when the region began its socioeconomic transformation after ending decades of war and conflict now seems to be an ever-distant goal.

Since competition over the use of limited natural resources now often cuts across national borders, it is vital for regional governments to have a good understanding of both the benefits and adverse impacts of resource exploitation within countries and across borders. In order to provide scientifically robust research to inform policy, the Sustainable Mekong Research Network (SUMERNET) was formed in 2005. The core functions of this research community are to jointly conduct multinational studies on major policy issues, build relevant capacities of researchers and policymakers, as well as engage with policymakers, planners and stakeholders in addressing sustainable development challenges in the Mekong Region.

Collaborative research and policy engagement

There are numerous research and development projects in the Mekong Region and across Southeast Asia focusing on specific systems, sectors, places and countries. But integrative regional-level analyses that compare or aggregate evidence and provide a platform to exchange fndings and experiences are lacking. Such integrative studies require extensive cross-country, regional and multi-level collaboration. In order to make these studies more effective, they must also link to policy, planning and practice, especially in their respective locations, but also, where possible, to national policy arenas.

The literature on development and environmental issues in the Mekong Region is growing. But there is a continued need to better understand the impacts and uncertainties from development and climate change across and in different countries. This volume brings together a new set of multi-country empirical case studies that contribute to this growing body of knowledge on the complexities of resource management and governance in the Mekong Region, against continued economic development and climate change. In addition, it identifies several successes and lessons for engaging with policy and planning process acrosss the region.

Organization of this book

This book is a collection of well-researched case studies across the Mekong Region. It contains 14 chapters from 12 cross-border (and in one case, cross-regional) collaborative research studies under four research themes by researchers from SUMERNET and its collaborative networks, including the Lower Mekong Public Policy Initiative (LMPPI) and the Asia-Pacific Network for Global Change Research (APN).

The first research theme, *Ecosystem services for rural development*, looks at the benefits people receive from local ecosystems. They include the provision of food and clean drinking water, as well as timber, fuelwood and protection from natural hazards. This theme takes existing knowledge and conceptual frameworks to ensure that policies and plans reflect relevant ecological processes in their formulation.

There are two chapters under this theme. The first 'Knowledge coproduction for recovering wetlands, agro-ecological farming and livelihoods in the Mekong Region' (chap. 2) looks at the challenges faced both by policy and on-the-ground practices on how to support wetlands and associated agro-ecological farming practices as an important foundation for regional resilience. This has been explored by learning from knowledge coproduction processes in three case studies in Thailand, Vietnam and Laos.

'Small (palustrine) wetlands in the Central Indochina Dry Forest Ecosystem and their conservation impact' (chap. 3) then investigates and compares the current extent of small wetlands with those mapped during the Second Indochina War in Kulen Promtep Wildlife Sanctuary, Cambodia, and Yok Don National Park, Vietnam. The chapter defines the characteristics of palustrine wetlands in the Mekong River Basin and their importance, then assesses human use and threats to these important ecosystems. This study will help decision-makers understand the potential impacts of development projects and land-use changes on the ecosystem in these areas.

The second research theme *Regional economic integration and social and environmental sustainability* aims to understand and address the effect of cross-border investments on land use and livelihoods in rural and natural-resource dependent communities, as well as the impacts of large transboundary or regionally-funded development projects. The fourth chapter 'The impact of the East-West Economic Corridor on the livelihoods of forest-dependent communities in Vietnam' investigates the impact of economic integration through a case study of forest-dependent villagers in Vietnam. Readers will understand better how these forest-dependent communities practice their livelihoods under increased regionalization brought about by the economic corridor, and why some communities are becoming better off while others are becoming more marginalized.

The next research theme *Climate-compatible development* aims to promote human development and ecological sustainability while considering the need to both mitigate and adapt to climate change in ways that are socially and gender-equitable. There are five chapters under this theme. The first, 'Development of national REDD+ strategy in Cambodia, Myanmar and Thailand' (chap. 5) documents and compares the processes, barriers and opportunities that Cambodia, Myanmar and Thailand have faced or will face in designing and implementing their national strategies for Reducing Emissions from Deforestation and Forest Degradation (REDD). This chapter provides insights and guidance for policymakers by identifying challenges and solutions on how key components for a national REDD+ strategy could be developed, with particular reference to improving the social and environmental well-being of forest-dependent communities in REDD+ participating countries.

'Rural households and climate change adaptation: Lessons from Cambodia and the Philippines' (chap. 6) draws on the experiences and lessons learned from and about rural households involved in climate change adaptation in both countries. Readers will gain a better understanding about the adaptation decisions of rural households and communities frequently affected by climate-related hazards. This chapter also evaluates household adaptation strategies and the extent to which they are building their community's climate resilience.

'The benefits of using rice straw-derived solid fuel to reduce open burning emissions in the Mekong Region' (chap. 7) presents an initiative focusing on the potential benefits of turning rice straw into cooking fuel in Thailand, Vietnam and Cambodia. The assessment analyses information gathered from primary surveys conducted in the selected key rice-farming areas in each country on current rice straw generation and use along with the emissions testing results of the rice straw fuel-cookstove systems developed as part of the study.

'Linking disaster recovery approaches and loss and damage systems in the Mekong Region' (chap. 8) explores the connections between disaster recovery approaches and addressing loss and damage through case studies of major flood disaster recoveries in the region. The chapter draws insights from three empirical case studies, including: the economic recovery of small and medium enterprises in Nonthaburi, Thailand, following the 2011 flood; residential clustering and other socio-ecological resilience-building approaches in Prey Veng, Cambodia, following the 2000–2001 floods; and the strategies for living with regular floods and livelihood adaptations by farmers in An Giang in the Vietnamese Mekong Delta, following the severe floods in 2000.

'Climate change and water scarcity in Champhone district, Savannakhet province, Lao PDR' (chap. 9) assesses the potential climate change and water scarcity impacts on physical/natural sites and livelihoods in the study site, and also reviews existing adaptation measures. The study involved many stakeholders and multiple research methods including a literature review/analysis, key informant interviews, focus group discussions and in-depth interviews, in order to recommend measures for adapting to climate change.

SUMERNET carried out four national assessment case studies in Cambodia, Myanmar, Thailand and Vietnam, respectively, under the research theme *Adapting to multiple and uncertain changes in the Mekong Region: Strategies for today and a +4C world*. On the basis of model ensemble projections, the Intergovernmental Panel on Climate Change (IPCC) (2013) projects increases in global mean temperature in the range of 0.3°C to 4.8°C by 2081–2100 relative to 1986–2005. Temperature changes over land are in addition projected to exceed changes over the ocean by a substantial ratio (1.4 to 1.7). Many scientists now view global increases exceeding 2.0°C as dangerous. The IPCC Special Report (2018) strongly encourages society to limit changes to 1.5°C. Change near the upper end of the IPCC's projections (4°C) are likely, however, in the absence of rapid and dramatic changes in global energy policy. The implication is that the region's inhabitants—including many alive today—and much existing or planned public infrastructure will be directly exposed to dangerous levels of climate change.

This research theme aims to understand the challenges from the multiple and uncertain changes in the current climate and under a scenario of +4°C. These scenarios are used to challenge and improve existing strategies and plans using the Robust Decision Support (RDS) framework (Groves and Lempert 2007). The RDS applies a participatory framework to integrate the natural, social, and political aspects of water resource management in a quantitative model for Integrated Water Resource Management (IWRM). RDS has been widely used to support long-term water planning under a wide range of uncertain climate scenarios (Mehta et al. 2014; Bresney and Escobar 2017).

'Assessment of hydrology for agricultural development based on climate change impacts in Prek Thnot River Basin, Cambodia' (chap. 10) assesses the combined impacts of climate change, land-use changes, and upstream hydropower development on water resources during the dry season in the Prek Thnot River Basin. The RDS framework has been applied to identify a set of potential adaptation strategies to these impacts. The findings from this chapter will contribute to the Cambodian government's policy on agricultural development in this basin.

'Chindwin River Basin: Water scarcity amidst plenty' (chap. 11) documents a case study that applied the RDS framework to water security issues in the Chindwin River Basin in Myanmar. A multi-stakeholder participatory approach was used to explore the uncertain impacts of climate change, land-use change and population growth on key aspects of water security. The study team aimed to assist policymakers from different agencies and other stakeholders to identify robust strategies to address droughts under highly uncertain future climate conditions in this basin.

'Application of Robust Decision Support (RDS) for water scarcity management in Northeast Thailand' (chap. 12) assesses the application of the RDS framework in the Huay Sai Bat River Basin to explore the feasibility of multiple drought management policies under a wide range of uncertainties, including climate and land-use change. Water allocation and use in various sectors, such as in agriculture, households, industry and the environment, were estimated using the Water Evaluation and Planning (WEAP) system under various scenarios developed through a series of consultative meetings with a wide group of stakeholders.

'Addressing urban water scarcity in Can Tho City amidst climate uncertainty and urbanization' (chap. 13) aims to identify key stakeholders and tools to support effective urban water management, build a complete multi-agent model to evaluate the present and future scenarios, as well as engage concerned stakeholders to ensure the research results will be used for future decisions in addressing urban water management challenges in Can Tho City in the context of climate change, fast population growth, and economic development.

This volume concludes with a synthesis chapter (chap. 14), emphasizing that the pursuit of sustainability must continue to take place at multiple levels of governance and society.

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2

Knowledge coproduction for recovering wetlands, agro-ecological farming, and livelihoods in the Mekong Region

Carl Middleton, Kanokwan Manorom, Nguyen Van Kien, Outhai Soukkhy and Albert Salamanca

The Mekong Region contains extensive wetlands of high levels of biodiversity that have long provided a wide range of ecosystem services that are equally important to human well-being (ADB 2012). In many cases, these wetlands have long been important for agro-ecological production, including rice and vegetable farming, livestock raising, fishing and aquaculture, and the collection of non-timber forest products (NTFPs), thus supporting local livelihoods and economies (MEA 2005; Wezel et al. 2009; Arthur and Friend 2011). Unfortunately, many wetlands in the Mekong Region have been degraded or even lost, largely due to agricultural intensification, large-scale water infrastructure development, and land use changes associated with urbanization (Hughes 2017). The extensive loss of wetlands is a threat to sustainable economic development through the loss of core ecosystem services that they provide. It also threatens the enjoyment of a range of human rights, including the rights to life, health, food, water and culture (Knox 2017). When traditional wetlands agro-ecological practices are lost, so too are the local knowledge and culture associated with them.

Addressing complex problems such as the loss of wetlands requires gathering and activating a range of different types of knowledge, including scientific (expert), local, practical, and political (van Kerkhoff and Lebel 2006). In this chapter, we present three case studies of knowledge coproduction research in Thailand, Vietnam and Laos aimed at the more inclusive ecological governance of wetlands degraded by large-scale water infrastructure and the recovery of associated agro-ecological systems and livelihoods. We consider knowledge coproduction to be the dynamic interaction of multiple actors, each with their own types of knowledge, who coproduce new usable knowledge specific to their environmental, sociopolitical and cultural context and that can influence decision-making and actions on the ground (Schuttenberg and Guth 2015).

The first case study focuses on collaborative wetland zoning and educational tourism at the Rasi Salai and Hua Na irrigation projects in Si Sa Ket province, northeastern Thailand. The second case study addresses four floodplain floating rice–vegetable agro-ecological systems in An Giang province and Dong Thap province, in the Vietnamese Mekong Delta. The third case study is on organic rice production in two villages in Xayboury district, Savannakhet province, Lao PDR. All three case studies were selected on the basis that they have experienced wetland degradation due to water infrastructure projects which have had adverse impacts on farmers and fishers whose livelihoods were linked to the wetland ecosystems, as well as the willingness of various boundary partners to engage in the project.

Van Kerkhoff and Lebel (2006: 448) argue that it is "the interaction between research and other sources of knowledge that is often crucial for understanding the role of research-based knowledge in action." In other words, producing expert knowledge alone is not enough to result in competent decisions and robust solutions (Cash et al. 2003). Multiple state and non-state actors must often collaborate to identify and implement solutions (Lemos and Agrawal 2006), although where there are divergent interests, values or beliefs between actors, contestation is the more likely outcome (Smajgl and Ward 2013). Indeed, expert knowledge may be treated with suspicion by civil society and community groups that consider it aligned with powerful state and private sector agendas (Wells-Dang et al. 2016). In mainland Southeast Asia, various forms of local research have emerged since the 1990s, including *Tai baan* (villagers' research) sometimes deployed as a "counter-hegemonic" response to expert knowledge (Scurrah 2013). In other cases, local knowledge has been documented in collaboration with universities (Manorom 2009) or the state, as in the case of Community Health Impact Assessment in Thailand (Middleton et al. 2017).

There is a growing body of literature exploring how designed knowledge coproduction processes that catalyze interaction among researchers and multiple state and non-state actors can create usable knowledge for action towards inclusive and sustainable development (van Kerkhoff and Lebel 2006; Clark et al. 2016). Here, knowledge coproduction is understood as both a governance strategy and a research strategy (Schuttenberg and Guth 2015).

Researchers have already amassed insights into how to design knowedge coproduction processes within complex environmental resource governance environments (van Kerkhoff and Lebel 2006; 2015; Frantzeskaki and Kabisch 2016). For example, Schuttenberg and Guth (2015) propose the need to consider: individual and organizational co-productive capacities; the socio-ecological system context; and the co-productive process, each of which contribute towards attaining immediate, intermediate and long-term goals. They emphasize that goals can only be achieved when there is a shared understanding of the problem and a genuine constituency formed to solve it (see also Lang et al. 2012). This requires appropriate representation, capacity, trust, and commitment to learning. The process involves iterative stakeholder interaction “which facilitate a shift from disparate, self-focused perspectives of a problem into a holistic, collective framing” (Schuttenberg and Guth 2015:15), and processes of social learning that integrate diverse knowledge systems. Frantzeskaki and Kabisch (2016) highlight that for successful knowledge coproduction, processes should encourage: openly shared knowledge; inclusiveness to multiple types of knowledge; and knowledge that is perceived as legitimate. They furthermore emphasize that knowledge produced through the process should ultimately be usable (i.e. it can directly influence decisions), and actionable (i.e. applicable and relevant).

In this chapter, we argue that the knowledge coproduction approach enables research to move beyond weak forms of “participation” and towards social learning that builds trust, partnership and ownership among actors, and can generate innovative solutions for wetland and livelihood recovery. The chapter is structured as follows. In the next section, we outline the overall research methodology. Then, in the following three sections we detail the research process, results and outcomes for each case study in turn. In the final sections, we discuss and conclude on the implications of the research.

Methods

Our methodology draws upon recent knowledge coproduction literature. We aimed for a "learning mode" of knowledge coproduction (van Kerkhoff and Lebel 2006) where researchers engage boundary partners in iterative processes of research and action; researchers sometimes took on the role of facilitator, whilst also providing expert knowledge input at times. Simpson et al. (2015) observe that collaborative processes open up the possibility of "challenging and changing stakeholder interests and positions, and for gaining the acceptance of compromises and trade-offs that are necessary for good problem-solving," although it is dependent upon the uncoerced convening of boundary partners in the first place. Whilst power imbalances will inevitably persist throughout the process (Schuttenberg and Guth 2015), this mode entails a conscious attentiveness to power relations through the design of the process, in particular to ensure inclusivity (van Kerkhoff and Lebel 2015). To the extent possible, as academic researchers, we were reflexive of our own positionality in the process. In the eyes of our boundary partners, as academic researchers, we were mostly viewed as holding relative objectivity and authoritative knowledge. Indeed, it is this (perceived) position—together with a long-standing relationship with some or all of the boundary partners—that enabled each research team to convene the knowledge coproduction process.

In each case study location, boundary partners were first identified by the research teams including communities, government agencies, and civil society groups. In the case of Thailand and Vietnam, the research teams already had strong relationships with these groups, whilst in the Laos case study the research team had a connection with a local government agency (table 2.1).

Table 2.1. Case study locations and boundary partners

	Rasi Salai & Hua Na dams, Si Sa Ket Province, Thailand	Floating rice, An Giang & Dong Thap provinces, Vietnam	Organic agriculture, Savannakhet province, Laos
Boundary partners			
Community	Community leaders from Nong Kae sub-district	116 households growing floating rice	25 farming households
Civil society	Khon Taam Association, Taam Moon project	Farmers' association at four communes, and district (mass organization)	
Local government	Nong Kae sub-district Administrative Organization	Vinh Phuoc and Luong An Tra People's Committee (commune), Tri Ton district People's Committee; My An and Tan Long People's Committee	Xayboury District Agriculture and Forestry office (DAFO) staff
State agencies	Royal Irrigation Department (RID), and several related line agency offices (Natural Resources and Environment; Forestry; Fishery; Livestock)	Department of Environment and Natural Resources and Department of Agriculture and Rural Development	Provincial Agriculture and Forestry Office (PAFO) and DAFO
Private sector		Rice producers, traders and nutritional business in Long Xuyen and Can Tho cities, tourist companies (Vietgreen Tour)	Resettlement Management Unit of the Nam Theun 2 Power Company (NTPC)

In each location, we first undertook qualitative scoping surveys with each boundary partner to define the diverse visions, goals, values and beliefs towards the wetlands and the associated agro-ecological farming system. An initial analysis defined areas of agreement and divergence among boundary partners (Smajgl and Ward 2013). This led to inception workshops in each location that brought together all partners and initiated a process of co-framing the problems faced. At the workshops, participants shared perspectives and deliberated goals and potential research projects. The inception workshop and subsequent activities and meetings can be understood as intentionally created "arenas of knowledge coproduction" (van Kerkhoff and Lebel 2006) (see discussion). Within this arena, we brought together different groups of actors, cognizant of their different interests and relative alliances and networks (van Kerkhoff and Lebel 2006; Simpson et al. 2015).

Following the inception workshop, divergent pathways were taken in each country, according to the proposed project emerging from the inception workshops. Details are discussed in each case study below, where we outline the background and study area; the research process; and outcomes. We undertook activities with our boundary partners from October 2014 to March 2017, as detailed below. Documentation of the process was via qualitative interviews, recorded observation, and documentation of the activities and meetings. At the mid-way and end points of each project, most-significant-change interviews were conducted with selected boundary partners.

Northeast Thailand: Collaborative wetland zoning and educational tourism

In 1993, the Rasi Salai irrigation dam was built on the Mun River in Si Sa Ket province, Northeast Thailand—the dam would lead to over two decades of, at times, intense conflict between the communities whose livelihoods were harmed by the project and the government agencies that built and operated it. The dam was built without an environmental or social baseline assessment or an Environmental Impact Assessment, and has been estimated to irrigate only 1,600 ha of the originally planned 5,500 ha (Living Rivers Siam 1999; 2000). The project's reservoir inundated around 10,000 ha of a wetlands area locally called *Pa Boong Pa Taam*, which was important for rice and fishery production, vegetables and herbs, and cattle grazing, with impacts on livelihoods (Sretthachau et al. 2000).

In response to the construction of the Rasi Salai dam, affected communities organized protests, including occupying the dam area for 189 days in 2007, after which the government began to provide long-promised compensation. Since then, conflict surrounding the project has gradually de-escalated, although it occasionally still flares up. A Participatory Social Impact Assessment (PSIA) was finally published in 2009, and negotiations began on how lost livelihoods could be recovered (Manorom 2009). Based on the recommendation of the PSIA, the Ministry of Agriculture and Cooperatives in partnership with Ubon Ratchathani University has supported, since 2012, activities to recover degraded wetlands for food security and ecological services, demonstrate local development activities (organic agriculture/green market), and promote integrated farming systems and fish conservation, and conduct information and education campaigns on wetland conservation. To coordinate negotiations with the government, communities affected by the Rasi Salai dam, together with communities affected by a second dam called Hua Na located approximately 80 km downstream, formed the Taam Moon Association. As part of the compensation package, the Royal Irrigation Department (RID) provided 30 *rai*[1] of land to the Taam Moon Association and a grant to build a community learning center.

Study area

The research was undertaken where Rasi Salai is located, in Nong Kae subdistrict (NKS). NKS is mostly downstream of the dam, and has also been impacted by the Hua Na dam reservoir downstream. NKS comprises of 17 villages with a population of 7,708 people. Hydrologically, NKS is a floodplain of the Mun River, with a diversity of wetland ecologies. The main occupation in the area is agriculture, with the most important activities being wet-season rice farming, dry-season rice farming that relies on water pumped from ponds in the wetlands, vegetable cash crop production (onions, garlic and chili), and livestock raising (cattle, poultry). Other activities include fishing; handicrafts; and the collection of products from the forest and wetlands. The younger generation tend to migrate to work in urban areas, as well as to access higher education. Meanwhile, middle-aged and elderly family members stay behind to farm and take care of the children.

Many community members in NKS who have lost farmland and wetlands have been highly active in social movements in Northeast Thailand over the past 20 years. As a result, they have: experience and a deep knowledge of the concept of participation; developed skills to articulate their claims and negotiate with the government; and have a sophisticated analysis of the issue of "development" in Thailand, and what their rights are, including under the various iterations of Thailand's Constitution.

Process

The Mekong Sub-region Social Research Center (MSSRC), Ubon Ratchathani University team, who are the conveners of this sub-project, held several rounds of individual meetings and interviews with each boundary partner identified in table 2.1 in February 2015 to discuss their values and vision for wetland recovery, and to identify shared visions and potential collaborative research projects. These interviews informed the design of a joint workshop, held in late March 2015 with 18 participants from nine boundary partners. Following a presentation analyzing the findings of the scoping survey by MSSRC, presented to key village leaders and boundary partners, subsequent discussion among the boundary partners explored the values of the wetlands, the impacts of the Hua Na and Rasi Salai irrigation dams, and the importance of recovering the wetlands. There was broad agreement that: 1) wetlands have been dramatically declining both in terms of quantity (one-third of the whole area around the Rasi Salai dam was identified as affected areas) and quality (degradation or loss of wetlands have harmed local livelihoods that depended on the wetlands); 2) there is a lack of coordination to manage and recover wetlands; 3) there are baseline data gaps on the wetland in terms of biophysical and socioeconomic data; and 4) there remain challenges on how to manage and recover lost wetlands, including flooded forest, fishery, aquatic resources, and dry-season rice farming in the wetland that have already been compensated for by RID, as many community members have continued to use the areas.

From this meeting, all boundary partners committed to work together on a research project. Two follow-up workshops in April 2015 led to an agreement that the research would focus on two themes:

- Collaborative wetland zoning, on the basis that there was a shared perceived need to clearly categorize the wetland area affected by the Rasi Salai dam, and designate permitted uses of particular areas within it. The focus would be on areas already compensated for by RID, and would balance community use with conservation objectives.

- Educational ecotourism, which was particularly supported by the community-based organizations, who had recently opened the "community learning center" near the Rasi Salai dam.

In mid-June 2015, another meeting was held to finalize the wetland zoning research strategy, which included a larger number of community leaders from NKS and other community-based organizations and government boundary partners. They prepared a resource mapping form that used Google maps to locate the data gathered. The research design allowed for the diverse forms of knowledge of those involved, ranging from GIS techniques by the government agencies, to knowledge of local ecosystems and their uses among the communities. From 20 to 22 June, the mapping exercise was undertaken in three locations: upstream of the Rasi Salai dam, in the flooded zone and non-flooded zone; downstream of the dam; and beyond the NKS area on the Naam Seiw River, a tributary of the Mun where community members also utilize natural resources. In three subsequent workshops, the group verified the data and agreed that there is a need to clearly categorize the wetland areas affected by the dam, and designate permitted uses within them.

The degree of collaboration between the state and non-state boundary partners in Rasi Salai was unprecedented, and the ongoing interaction through the collaborative research, as well as the knowledge generated, built a measure of trust in each other. However, it soon emerged in the post-mapping meetings that wetland zoning remained a contested issue between the groups participating, and also among community members outside of the meetings. Some land that had received compensation in the past from RID remained in private use or subject to disagreement over the level of compensation, whilst the RID's general position was that this land should now be either allocated for conservation or collectively used by the community. In addition, long-standing disagreements over the level of water in the reservoir, which in turn relates to access to currently inundated land, also re-emerged. Thus, despite the measure of trust generated on all sides through the collaborative research, it became apparent that more time and resources beyond the scope of the project would be required to work through all the issues related to wetland zoning. Furthermore, a civil society leader trusted by many community members and who could also maintain a connection with the state partners passed away during this period, leaving a significant gap in the relationship.

For educational ecotourism, over a series of meetings, tourism experts from the Faculty of Liberal Arts, Ubon Ratchathani University, worked with the boundary partners. In this project, civil society and community members emerged as most active over time, as it was intended that students would come to stay at the community learning center near the Rasi Salai dam. However, the government agencies generally supported the initiative, and met visiting students in their office as a part of the educational tourism agenda. The community members prepared an ecotourism brochure, identified tourist hot spots and stories associated with each place, designated tour guides, and managed the necessary logistics.

The educational tourism pilot was held from 14 to 15 November 2015 with masters-level students from Chulalongkorn University. Activities included: learning about the Taam Moon Association; a group discussion with dam-affected people; visiting the RID office to meet government officials; experiencing wetland livelihood activities, such as collecting wild potatoes and vegetables; listening to traditional music; making merit at the local temple; visiting and learning about the spirit forest; and a boat-trip through the wetlands. Following feedback from the participant students, the university team and community leaders revised the design. Subsequently, a “grand tour” was organized in March 2016 with many local boundary partners, including government officials, complete with a booklet “Touring Around Wetlands” (fig. 2.1). Since the “grand tour,” at least three more tours were organized in the following six

Figure 2.1. “Grand Tour” participants’ booklet

months that have included university students, NGOs, academics and independent researchers, and now that the design is complete more tours can take place.

Outcome

The most visible outcome from the process was the shift from conflict to a greater degree of cooperation towards the Rasi Salai dam among boundary partners. Given the past history of social conflict in the area between the government agencies and the affected communities, the boundary partners were pleased to be part of the joint research, as they had never made this happen before. Trust was generated through the social interaction and joining activities of the project, such that a degree of cooperation emerged to resolve conflict over the wetland agro-ecosystems. This led to all boundary partners agreeing that the wetlands must be managed based on both local and scientific knowledge and participatory methods, although more remains to be done about this issue.

The educational tourism project has raised the profile of the wetlands as a resource for local livelihoods and ecological services for the outsiders who visited. It also generated legitimacy for wetland protection among the boundary partners. Community members could generate income from the activity, whilst government officers accomplished their mandate on sustainable wetland management.

Vietnamese Mekong Delta: Floating rice

Deepwater rice—also known as floating rice—is native to Vietnam's Mekong River Delta, and, in the past was grown widely across its floodplains, particularly in the Long Xuyen Quadrangle and the Plain of Reeds. Floating rice begins to be grown in June with the start of the rainy season. River floodwater arrives in mid-August, during which time the rice stalks rapidly grow with the rising water levels. When the water level recedes in November, the rice stalks lie flat on the ground and they flower and produce grain which is then harvested in December. No pesticides, and only a small amount of chemical fertilizer (less than 50 kg of nitrogen/ha), are used (Nguyen et al. 2015). During the dry season, various vegetables and crops are grown, including cassava, leeks, pumpkins, chili, maize and mung bean, depending on the soil type and relief.

Before 1975, the total area of floating rice was estimated to be greater than 500,000 ha; by 1994, this had been reduced by 80 percent, and, as of 2012, only very small pockets of tens of hectares remain, mostly in An Giang province (Nguyen et al. 2015). The reduction is linked to Vietnam's agricultural policy of promoting agricultural intensification, including the introduction of high-yielding varieties (HYV) of rice and extensive dike construction (Nguyen and Pittock 2016). This has increased food production for domestic consumption and export, but also created a range of environmental and health problems including rising agrochemical pollution and reduced soil fertility (Käkönen 2008). There is a growing recognition among farmers, researchers and the government about the need for more sustainable agriculture. Some have focused on promoting integrated pest management and rice–fish farming that modifies existing practices (Berg et al. 2017). The revival of floating rice has also received some consideration (Nguyen and Pittock 2016).

Study area

The Research Center for Rural Development (RCRD) at An Giang University organized a knowledge coproduction process around the benefits and challenges of floating rice agro-ecological systems, including resilience during a drought year in 2015 when the Mekong's floodwaters were very low. RCRD collaborated with floating rice farming households in four communes:

- 30 households in Vinh Phuoc and Luong An Tra communes of Tri Ton district, An Giang Province, farming about 100 ha in total of floating rice;
- 43 households in My An commune of Cho Moi district, An Giang province who cultivate about 26 ha of floating rice; and
- 53 householders in Tan Long commune of Thanh Binh district, Dong Thap province who cultivated about 53 ha of floating rice.

Process

In order to map the opportunities and challenges faced by floating rice, and to co-design an intervention, first a participatory rural appraisal (PRA) was undertaken between December 2014 and March 2015 in each commune. In addition to the 126 farming households who cultivate floating rice, the RCRD team worked with the state agencies identified in table 2.1. A key expectation of these boundary partners emerging from this initial assessment was the desire to increase the market price of floating rice. Suggestions were made to build better relationships with rice traders and sellers, and also to promote awareness of the benefits of floating rice among consumers. Therefore, in two workshops held at An Giang University in February 2015 and Cho Moi district in June 2015, private sector rice traders and sellers from Long Xuyen and Can Tho cities were also invited, as well as the local media.

Although relative to HYV rice the yield of floating rice is low, when combined with dry season agriculture (cassava/ leeks/ chili/ corn) the PRA results indicated that the annual economic value of floating rice-based farming generated more financial returns to farmers per 1,000 m^2 (*cong*) (table 2.2). For the purpose of comparison, Table 2.3 details the cost–benefit ratio for other farming systems in the Vietnamese Mekong Delta, including additional studies on floating rice detailed in Nguyen et al. (2015).

Table 2.2. Cost–benefit analysis of floating rice farming systems

Locations	Farming systems	Net return (VND/1000m^2)	Cost–benefit ratio
Vinh Phuoc & Luong An Tra communes	Floating rice–cassava	4,425,000	1.81
	Floating rice–leeks	24,895,000	1.68
	Floating rice–chili	17,745,000	2.68
Tan Long commune	Floating rice–chili	16,763,314	1.12
My An commune	Floating rice–sticky corn–baby corn–baby corn–cattle	18,557,500	0.48
	Floating rice–sticky corn–baby corn–baby corn	11,025,000	1.24

Table 2.3. Cost–benefit analysis of rice farming systems

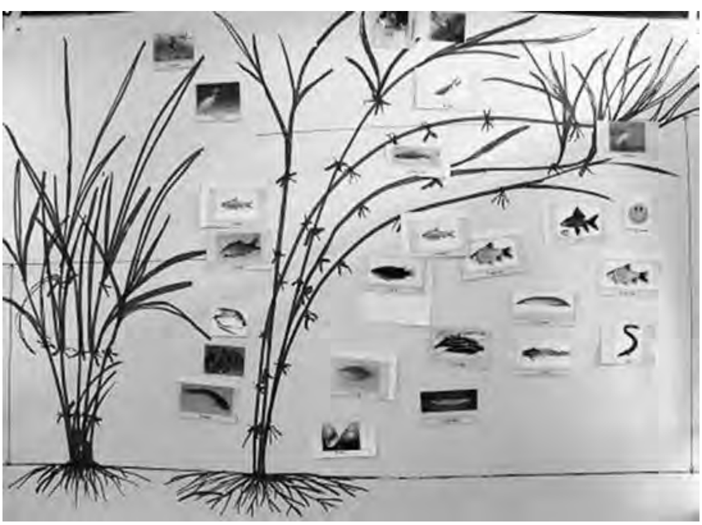
Locations	Farming systems	Net return (VND/1000m^2)	Cost–benefit ratio
Chau Phu district	3 rice crops/year	4,827,200	0.71
Thanh My Tay commune	2 rice crops/year	2,484,363	0.62
	2 rice crops + one cattle/year	13,959,780	0.56
	Chili + one cattle/year	15,685,217	0.54
	Chili + one *Sesbania sesban* crop	7,858,700	0.62
	2 rice crops + one *Sesbania sesban* crop	6,133,263	0.71
My Phu commune	2 rice crops	2,620,881	0.57
	2 rice crops + one cattle/year	11,960,101	0.50
	Maize–mung bean	11,047,000	1.07
	Mung bean–pumpkin–rice	4,496,826	0.40
	Maize–maize	21,014,000	1.75
Tri Ton district	Floating rice–cassava	4,425,000	1.81
	Floating rice–leeks	24,895,000	1.68
	Floating rice–chili	17,745,000	2.68
Thanh Binh district – Dong Thap	Floating rice–chili	16,763,314	1.12
Cho Moi district	Floating rice–sticky corn–baby corn- baby corn- cattle	18,557,500	0.48
	Floating rice–sticky corn–baby corn- baby corn	11,025,000	1.24

Source: Nguyen et al. 2015.

The PRA and subsequent workshops identified a range of qualitative values from floating rice production:

- Floating rice creates large amounts of straw which in the dry season is used as a mulch to cover soils on which vegetables are grown. This conserves soil moisture, reducing the need for watering, and adds to soil organic matter. As a result, farmers can save money on hired laborers and inputs.
- Floating rice during the flood period provides habitats for freshwater black fish, such as snake head, and white fish for daily consumption. They also make fish sauce during this time to store for home consumption for the year. These freshwater fish provide rich protein and micronutrients.
- In places where floating rice was reintroduced, wild freshwater fish returned. In contrast, there were less fish or even no fish in the HYV rice fields nearby using high dike compartments (fig. 2.2).
- Allowing natural flooding in the fields increases alluvial sediment deposition, reducing the need for chemical fertilizers.
- Income is diversified, as land used for floating rice is turned to vegetable production during the dry season.

Figure 2.2. Diversity of fish, crustaceans, and amphibians recorded by farmers at the stakeholders' workshop in Cho Moi district, June 2015



A shared objective among boundary partners that emerged from the PRA and workshops was to improve the marketing of floating rice. Reflecting on the qualitative values above, they proposed to emphasize that floating rice is nutritious, tasty and almost without chemical input. The latter is particularly salient with consumers in Vietnam who are increasingly concerned about food safety. From the early stages of the project, it was apparent that the marketing of floating rice was a key priority of all boundary partners. Thus, in December 2014, at the provincial fair in Long Xuyen city, 35 floating rice consumers were interviewed to understand their perceptions and willingness to pay for floating rice. 31 percent said they were willing to pay a higher price for floating rice, with a key reason being that the rice was perceived as good for health and "clean", with no chemicals. At the fair, and subsequent similar events and individual meetings, farmers could connect directly to consumers and rice traders.

Before the project in 2014, in Tan Long and My An communes, most farmers cultivated floating rice to feed animals (stems from rice) or to sell to local customers who are generally older people or religious groups in various temples in Ho Chi Minh City, and in other sites they only sold to local farmers at a low price (VND5,000 per kg). From 2014 to 2015, when the farmer groups began marketing floating rice including via the local media, conferences, workshops, and at the floating rice harvest festivals, the price of paddy rose to VND 12,000 per kg–15,000 per kg. Many of the farmers have now signed contracts with companies who will buy their harvest, package and sell it in Ho Chi Minh City, and trust between farmers, researchers and business has improved. This is a pathway for promoting chemical-free rice farming for smallholders in the region.

In 2015, a major challenge experienced by floating rice farmers was that the level of the Mekong floodplain inundation was very low, leading to much of the floating rice paddies being destroyed by rats (VNS 2015). RCRD conducted interviews with the floating rice farmers in August 2016 to evaluate how they could adapt to and cope with droughts. Whilst the drought severely affected floating rice production, it was found that growing vegetables in the dry season instead resulted in a resilient farming system so that farmers could recover from the shock of income loss following the serious drought. Most farmers interviewed said they would continue to grow floating rice because they needed the straw for dry season crops. They also noted that their income had improved since 2014 due to a significant rise in the price of floating rice. The floating rice-based system is diversified, so farmers can mitigate the impact of droughts with other income sources such as vegetable growing.

Outcome

The research process helped farmers—and the other boundary partners—to appreciate the value of floating rice for safe food production, maintaining biodiversity, recovering inland fisheries, improving the environment, maintaining good soil quality, and providing other necessary resources (rice straw) for crop production in the dry season. Based on interviews with floating rice farmers, the co-designed and implemented research made them feel more connected and more trusting towards the government and private sector. The project has also provided the farmers with links to consumers who would like to purchase the floating rice, which, in the process, increased the price of the rice sold. Consumers were willing to pay a higher price because they believe that floating rice is healthier. The nutritional value of floating rice and its ecosystems services were communicated via local and national media (newspaper and television) to the wider public.

The local government also became more aware of the importance of floating rice conservation. During the research period, the An Giang Provincial Department of Agriculture and Rural Development targeted to conserve 500 ha of floating rice by 2030 in agricultural development policies in Tri Ton district (AGDARD 2014). Recognizing the negative impact of agrochemical-intensive HYV rice production on the biophysical environment, one of the strategies of the Mekong Sustainable Development Goals is the restoration of traditional agro-ecological agriculture (Government of Vietnam 2017).

To cope with future uncertainty (droughts and floods), the local government of Tan Long, Vinh Phuoc and Luong An Tra communes now plan to upgrade their low dike systems to regulate water levels for floating rice. Also, the Tri Ton district People's Committee has developed a long-term program to promote agro-ecotourism at floating rice conservation sites to improve non-farm income for farmers.

Laos: Organic rice in Savannakhet province

Savannakhet is the most important rice-producing province in Laos, growing approximately 27 percent of the country's total production (DOA 2016). In recent decades, the intensity of agrochemical use has risen for dry-season rice, and to a lesser extent, wet-season rice. Recent Government of Laos (GoL) policy, however, has encouraged "Good Agricultural Practice" (GAP) for rice production that are broadly aligned with organic agricultural practices, although in some cases limited agrochemicals may be applied (although not in our study area). In October 2017, following several policy commitments by the GoL over previous years, China announced it would increase its import of GAP rice from Laos from 8,000 t in 2016 to 20,000 t in 2020 (*Laotian Times* 2017). Farmers from southern Savannakhet province officially began exporting rice to China in December 2015 (Xinhua News Agency 2016).

Study area

Our study area in Laos was located in Phonethan and Dong Yang villages in Xayboury district, Savannakhet province. Xayboury district is second only to Champhone district in Savannakhet in terms of rice production, producing 62,901 t of wet-season rice and 49,910 t of dry-season rice in 2016 on 14,600 ha and 8,928 ha, respectively (DOA 2016). Both villages are principally Lao Loum (i.e. ethnically lowland Lao), and mainly engaged in rice farming, although many villagers also seasonally migrate to work in Thailand. Fishing and livestock raising are also important secondary occupations. Phonethan village has a registered population of 452 people in 75 households, and Dong Yang village has a registered population of 321 people in 70 households.

Both villages are located near the Xe Bang Fai River that flows through Khammouane and Savannakhet provinces. Since 2010, the flood regime of the river has been altered by the operation of the Nam Theun 2 (NT2) dam, which has impacted water levels, rice production, fisheries, riverbank gardens and wetlands (Baird et al. 2015). According to local villagers, in the past, it would take seven to eight days of heavy rain to flood the farmland of Phonethan and Dong Yang villages. However, since NT2, they say it now takes only between two to three days to submerge the rice fields due to the new river hydrology. This has been a sensitive issue and can be difficult for the community to raise with the GoL.

Process

In January 2015, researchers from the Northern Agriculture and Forestry College (NAFC) undertook a series of individual interviews with the key boundary partners identified in table 2.1. Similar to the other case studies, the visions and strategies for livelihood improvement were discussed with each group. From the interviews, it became apparent that improving agriculture was a key concern.

Subsequently, in March 2015, a workshop was organized at the District Agriculture and Forestry Office (DAFO) in Xayboury district for 16 participants representing all of the boundary partners. At the meeting, DAFO proposed to increase the value of agricultural production including via targeting export markets, improving technology, and promoting contract farming. The Resettlement Management Unit of Nam Theun 2 (RMU) proposed livelihood diversification strategies, such as fish and frog raising. Farmer groups proposed organic rice production with their own brand with a goal of increasing income, and it was this latter proposal that was agreed among all boundary partners. DAFO and NAFC offered technical support for the transition to organic rice production using GAP principles.

In May 2015, a meeting was organized with fifteen farmers from Phonethan village and nine farmers from Dong Yang village, NAFC and DAFO to detail the strategy for organic rice production. The farmers believed organic rice production would be low cost, offer higher market prices, be safer for the environment, produce healthier final products, and was aligned with the government's new policies to promote rice exports. They also said that they had experience of organic production in the past, as this was how they used to grow rice. They were also keen to utilize the natural resources available in the village (cattle and poultry manure, green waste and legumes).

To minimize risk, it was agreed that each family would plant one *rai* of organic rice, which ranged between 10 percent and 30 percent of their total land area. Reflecting a principle of knowledge coproduction, NAFC and DAFO provided training on the principles of GAP and how to produce organic manure and bio-extracts. The NAFC researchers and DAFO team also visited several times over the duration of the wet season (May–October 2015) to provide technical advice. As per the farmers' request, the organic rice production was designed to use local resources and utilized low quantities of input.

With a satisfactory yield from the perspective of the farmers from the first wet-season crop, organic production continued over three further seasons with the support of the project: the November 2015 to March 2016 dry season; May to Oct 2016 wet season; and November 2016 to March 2017 dry season. The number of participating farmers also grew, together with the area under production. In the first two seasons, there were 24 and 25 farmers cultivating 3.84 and 4 ha, respectively. In the final two seasons, there were 30 farmers cultivating 4.8 ha.

Outcome

Following the GAP transition, the calculated average yield was 2.3 t/ha for the rainy season crop in 2015,[2] which was satisfactory for the farmers especially given the soil was still in transition. Participating farmers expressed their satisfaction with the GAP system, with important reasons including: fewer inputs required during production, which were also available locally; more healthy food for producers and consumers; and better soil quality. The challenges encountered, however, included: the extra work required to produce GAP rice; the availability of local resources for fertilizers; and the difficulty of learning new techniques. Furthermore, although there is now a growing opportunity to sell organic rice to China, at present, the price increase for GAP rice compared to non-GAP rice is not significant; farmers consider an important next step to be to develop a brand and to market it so as to increase its market price.

Whilst the challenges and opportunities of GAP are relatively well documented, we suggest that the process of transition is also important. Farmers and DAFO both stated the project had enabled a closer collaboration through the knowledge coproduction approach, whereby new farming techniques were combined with local knowledge and existing practices and values. In the process, other issues could also be broached, such as the impact of the Nam Theun 2 dam upstream on farmers' livelihoods. Given the GoL's policy to promote GAP, based on the experience of our modestly scaled project, we suggest that building partnerships through collaborative research can benefit policy implementation and sustainability.

Discussion

The three case studies above reflect a range of types of degraded wetlands/floodplains and sociopolitical contexts within mainland Southeast Asia. Across this diversity, boundary partners were willing to engage in the knowledge coproduction approach, where the precise method was adapted to each particular context. In each case, we worked with boundary partners towards attaining a shared understanding of the real-world problem related to degraded wetlands, and how a research project could be collaboratively undertaken to contribute towards resolving the problem. Our own intention was to explore the possibility for collaborative approaches to work towards the resolution of complex problems, within which various forms of local and practical knowledge would be combined with expert knowledge to create new usable knowledge.

To catalyze knowledge coproduction, one key role of the researcher is to create "arenas of knowledge coproduction" (van Kerkhoff and Lebel 2006). In this project, these arenas included the workshops and other events that we organized, as well as interaction during the various research activities. Such arenas do not emerge spontaneously, but must be designed within the opportunities and constraints of existing power relations and through building trust among groups. Thus, a second key role of our research team was that of facilitator. Schuttenberg and Guth (2015: 15) propose as a principle for method design that "Even if there are power imbalances in the broader social context …, the coproduction process needs to create an oasis in which stakeholders are given an equal voice so that trust, creativity, and shared understanding can develop." In our approach, power asymmetries were acknowledged and, to the extent possible, reduced so as to encourage exchange and participation as equals. Within our process, for example, we emphasized the role of community members to define and legitimize research goals. As van Kerkhoff and Lebel (2006: 466) write: "power can no longer be ignored as it is intimately entwined with the ability to act."

Knowledge coproduction by definition involves combining together local and expert knowledge through a process of co-convened research. In this project, we incorporated—but did not overly emphasize—the introduction of academic expert knowledge into the knowledge coproduction process. Examples of academic knowledge include: the provision of technical knowledge of organic GAP techniques in Laos;

guidance on educational tourism from Ubon Ratchathani University in Thailand; and in all three cases input into the boundary partners' research designs where needed. We sought to emphasize how the boundary partners' interactions in themselves could produce new usable knowledge, while also contributing towards building trust and shared perspectives among them. For example, in the wetland resource mapping at Rasi Salai, the government contributed practical knowledge of GIS techniques, whilst the participating community members shared their local knowledge of ecologies and social practices in each place. As highlighted by Olsson et al. (2004; see also van Kerkhoff and Lebel 2006), the emphasis is on how boundary partners not only participate in knowledge production, but learn through the process of situating themselves and understanding a particular knowledge system within which they are embedded (and producing). Thus, boundary partners interactions among themselves both produces new knowledge *and* social learning.

Van Kerkhoff and Lebel (2015) state that the quality of relationship is an important factor in knowledge coproduction, and that often 'sub-optimal conditions' exist that can test these relationships when a knowledge coproduction initiative is undertaken. In each of our cases, there was an element of historical contestation and thus limited trust among boundary partners. This was most evident at Rasi Salai, given the history of the project, and to a lesser extent in Laos where Nam Theun 2 dam had affected the community. The case of Rasi Salai in particular can be considered an "unstructured" problem (Smajgl and Ward 2013, citing Hisschemöller and Hoppe 1996), where there is high factual uncertainty or disagreement, and conflict over values/ beliefs/ norms among boundary partners. In contrast to "structured problems" when there is little dispute, unstructured problems are complex and require extensive analysis, negotiation, and possibly conflict resolution. At Rasi Salai, trust-building was attained through the meaningful participation of and deliberations among the boundary partners, but also based on a tentative desire for closer cooperation emerging from the PSIA completed in 2009 (as discussed above). All the steps of the wetland zoning and educational ecotourism activities were openly discussed and agreed upon prior to their implementation. Without such deliberation and agreement, the joint activities could not have gone ahead. Once they did, further interaction helped build relationships and trust between boundary partners. In the case of Vietnam, meanwhile, the limited initial trust, in particular between the farmers and rice trading firms, was due to it being a new relationship, but once initiated by RCRD, trust rapidly grew as these boundary partners established practices of mutual benefit.

Conclusion

Agro-ecological farming has long been practiced in the Mekong region's productive and biodiverse wetlands. A contemporary challenge faced both by policy and practice is how to support wetlands and associated agro-ecological farming practices as an important foundation for regional resilience. This chapter has explored knowledge coproduction in three case studies in Thailand, Vietnam and Laos. We found that knowledge coproduction methodologies that meld together different types of knowledge, including scientific and local knowledge, have significant potential to produce usable knowledge for real-world problems. The process of co-identifying social challenges, research questions and research designs, achieved through a shared understanding among boundary partners, was necessary to proceed with the research itself. The role of a knowledge broker/facilitator/mediator, in this case our research teams, helped to build bridges between boundary partners and create "arenas of knowledge coproduction."

We found that once there was agreement to proceed with the research, which took multiple rounds of individual and group meetings, the interactions among participants in themselves increased trust, encouraging each actor to understand the problem from other points of view. This enhanced the possibilities for further collaboration, especially when there was concrete progress in addressing the real-world problem identified, as demonstrated in the Laos and Vietnam case studies, and in Thailand for educational tourism. However, entrenched conflicts, such as over wetland zoning at Rasi Salai dam, also reveal the limits of this approach. Thus, it is within limits that knowledge coproduction can contribute towards resolving social and environmental challenges achieved through building trust and partnership between boundary partners, generating usable knowledge and enabling social learning.

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Notes

1 1 rai = 1,600 m^2.
2 The average yield for GAP rice production in Savannakhet province was is 4.32 t/ha in 2015 (DOA 2016).

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3

Small (palustrine) wetlands in the Central Indochina Dry Forest Ecosystem and their conservation impact

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Wetlands are well known for their importance to biological diversity and ecosystem services. Yet palustrine or small wetlands within Southeast Asia have been little studied. This study sought to: survey Kulen Promtep Wildlife Sanctuary (KPWS) of Cambodia and Yok Don National Park (YDNP) of Vietnam to determine if palustrine wetlands existed; understand what characteristics defined palustrine wetlands in the Mekong River Basin; determine human use and threats to these ecosystems; provide information for decision-makers; and extrapolate results to the broader Mekong region.

This research examined 97 and 48 wetlands at KPWS and YDNP, respectively. All basins had hydrology, soils, flora and fauna that were of wetland origin. Both within and between wetlands, extensive variation existed in geomorphology, inundation periods, soil characteristics, plant community composition, faunal composition and human use. Collectively, all wetlands studied supported substantial biodiversity even though individual wetlands were often not diverse. Historically, palustrine wetlands were mapped by the United States military and likely exceeded 20,000 wetlands within the Central Indochina Dry Forest Ecosystem. Currently, many of these wetlands have been seriously impacted by intensive agriculture (especially large-scale rubber plantations), excessive disturbance or simple neglect. Conservation efforts should prioritize palustrine wetlands through creating new policy, updating the historical database to reflect current conditions, and developing an action plan that

maintains the remaining wetland systems for the benefit of all wetland species and populations.

Wetlands in the Mekong Region

Wetlands exist along a continuum between terrestrial and aquatic systems. As such, wetlands create habitats for species that utilize all points located along this hydrological gradient and collectively contain high species diversity. For wetlands typified by cycles of inundation and drying, primary productivity is also among the highest of any ecosystem known (Mitsch and Gosselink 2015). Wetlands arise from many origins (marine, estuarine, riverine, lacustrine or palustrine; Cowardin et al. 1979) but the focus of this chapter is on palustrine wetlands, which tend to be less than 8 ha., shallowly inundated, contain shorelines not formed by wave action and contain few salts of marine origin. Palustrine wetlands have been well studied as prairie potholes in North America (Van der Valk 1989), but are virtually unknown in Southeast Asia. In contrast, the large wetlands of Southeast Asia, like the Plain of Reeds in the Mekong Delta, are well known (Tran and Barzen 2016) and wetland classification systems have been developed for parts of Southeast Asia (Pham 2003; MacAlister and Mahaxay 2009). Yet palustrine wetlands have not been incorporated into any classification system used within the Mekong Basin. For example, many palustrine wetlands were sampled during a broad survey of toxic materials deposited throughout Southeast Asia (Tran et al. 2014; fig. 3.1a). Yet these wetlands are not depicted in a wetlands map produced by the Mekong River Commission (2010; fig. 3.1b). More specifically, Barzen (2004) estimated that 11,850 wetlands existed in 5,271,317 ha of deciduous *Dipterocarp* forest searched within the Central Indochina Dry Forest Ecosystem of Cambodia (Baltzer et al. 2001) even though none of these wetlands were mapped in recent wetland classification systems.

From the late 1950s to 1970 the US military created topographical maps in Cambodia and Vietnam that included wetland data. Recent aerial surveys relocated wetlands mapped by the military decades before so these wetlands must have been mapped with reasonable accuracy and be persistent (Barzen 2004). But are they true wetlands?

Generally, all definitions of wetlands include three components: wetlands have either standing water or saturated root zones during at least several months in a typical year; extended saturation creates soil conditions that reflect the absence of oxygen; and wet conditions tend to produce plants that tolerate extended periods of inundation (hydrophytes; Mitsch and Gosselink 2015).

If the areas mapped by the US military are palustrine wetlands they should have water, soils, and biota that reflect inundated conditions. An alternative explanation of wet areas mapped by the military is that they represented temporarily flooded forest that occurred during the rainy season only. Others hypothesized that these areas were bomb craters or wallows created by animals and therefore could be created anywhere in the forest. In northern Cambodia, the core of the former Angkor Empire, wetlands may also have been created by people for agricultural, husbandry or religious purposes a millennia ago.

If water bodies seen in the open forest are only random collections of temporarily ponded water then they are likely to add little biological significance or ecological function to the region because they are ephemeral and unpredictable in location. In contrast, if true wetlands, these small water bodies would contribute greatly to the region's biodiversity and perhaps drive many biotic and abiotic ecosystem functions. Currently, water infrastructure development and changes in land use are occurring rapidly in the region and are likely to alter any wetland ecosystem functions in the future. Without better knowledge of wetlands, decision-makers cannot understand the full impact of development projects in the dry forest ecosystem or estimate how the associated biological diversity and function of wetlands might be affected by proposed changes. The question, "Are these water bodies true wetlands?" thus becomes a central question to understanding threats to biological diversity in the broader Central Indochina Dry Forest Ecosystem.

Research objectives

The goal of this study was to: 1) survey Kulen Promtep Wildlife Sanctuary of Cambodia and Yok Don National Park of Vietnam to determine if palustrine wetlands existed; 2) understand what characteristics define palustrine wetlands in Southeast Asia, 3) determine how people use wetland resources and threats to these ecosystems; 4) provide information for decision-makers to understand potential impacts of development projects and land use changes; and 5) extrapolate results to the broader Mekong region. KPWS and YDNP were chosen as study areas because

Figure 3.1. Comparison of wetland locations between a) wetlands sampled in a regional study for organo-chlorines (Tran et al. 2014) and b) a map of wetland extent (Mekong River Commission 2010). Both studies focused on the Lower Mekong River Basin. Note the presence of numerous wetland locations in a) where no wetlands are depicted in b), especially in northern Cambodia.

Figure 3.1a. Wetland locations (Tran et al. 2014)

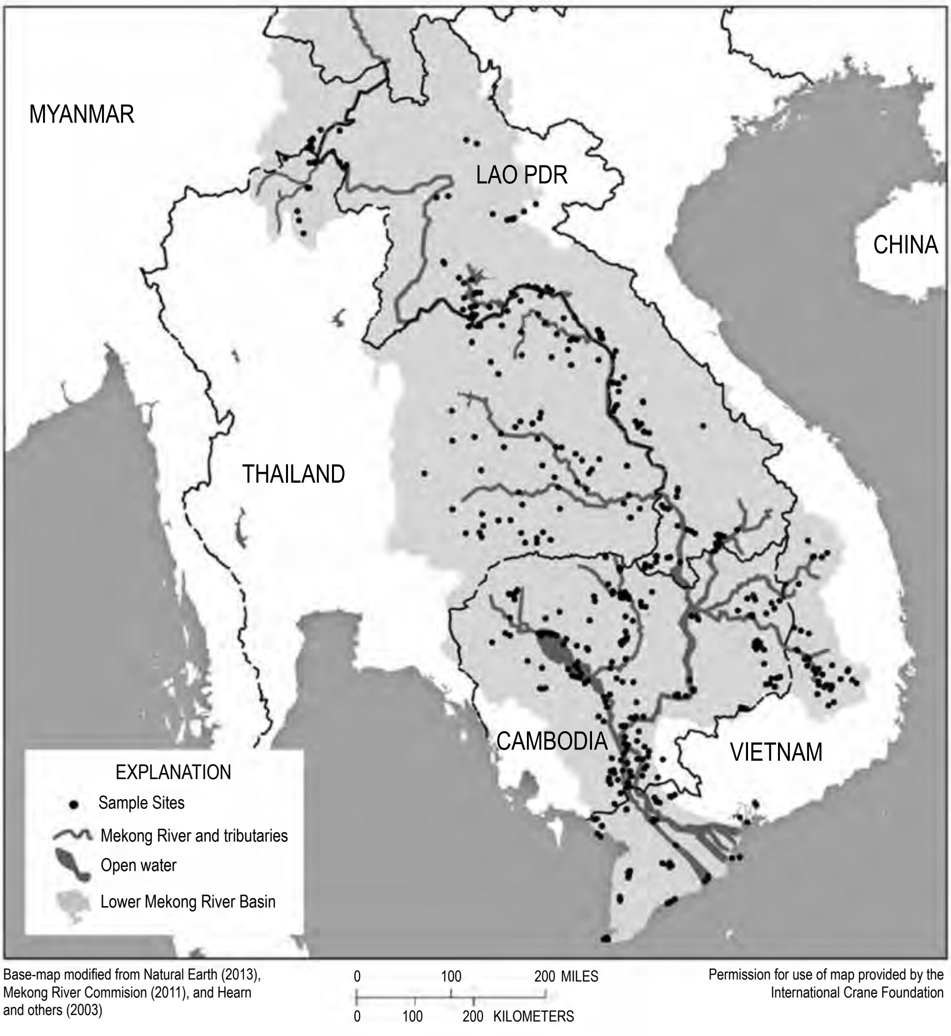
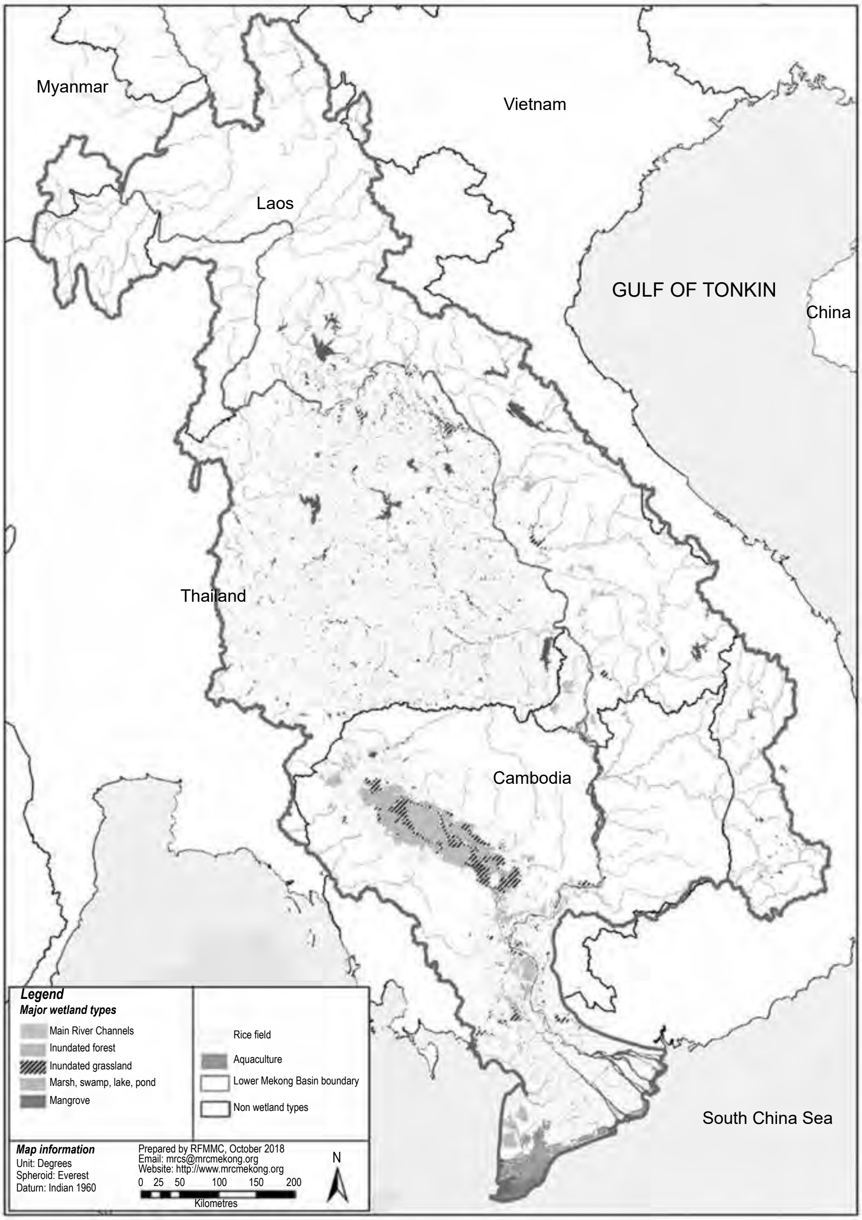


Figure 3.1b. Major wetland types of the Lower Mekong Basin (MRC 2010)



these protected areas contain large tracts of dry forest and numerous, divergent potential wetlands (Barzen 2004) that are representative of the Central Indochina Dry Forest Ecosystem (Baltzer et al. 2001).

Methods

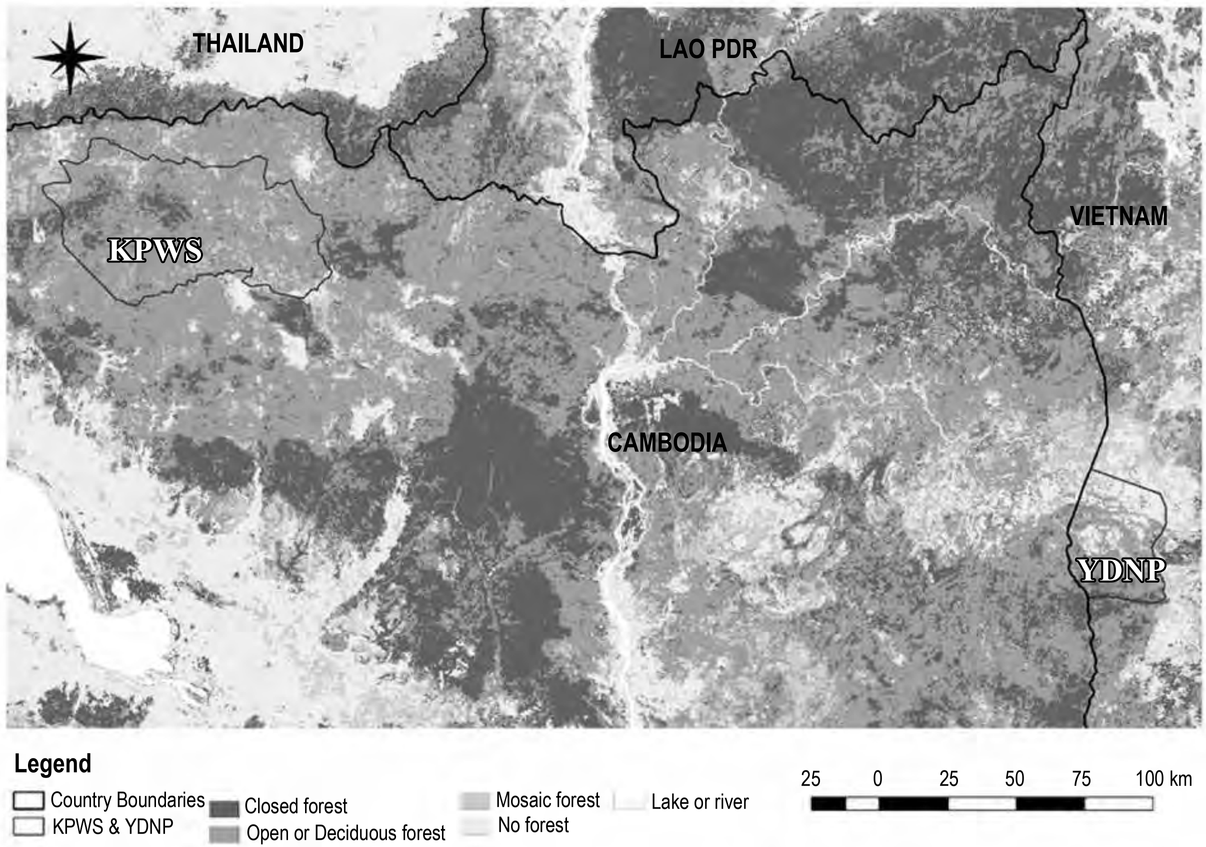
To study the hydrology, soils, flora, fauna and human use of wetlands this research project developed an interdisciplinary team of experts and students. In the lab, one group examined wetland distribution using Geographic Information System (GIS) tools. A second group examined soils, hydrology, plants and fish in the field. A third group surveyed birds in the same wet areas as the hydrology/soils/plant/fish group but on different days, and a fourth group interviewed people in villages nearby. Since the first objective of this study was to determine if the chosen study sites were true wetlands, the terms 'wet areas' or 'wet sites' were applied in the methods and results whereas language in the discussion reflects the conclusion of this paper.

Study sites

First researchers created a wetland layer for GIS by scanning all 1:50,000 scale maps produced by the US military from the late 1950s to 1970 for the northern half of Cambodia and for small segments of Lao People's Democratic Republic (Lao PDR), Thailand and Vietnam where these regions bordered Cambodia (Barzen 2004). Digital maps were then geo-rectified and then individual wetlands were digitized by hand. US military maps were purchased in local markets of Phnom Penh where vendors were selling military paraphernalia. US military maps were readily available in the year 2000. All the military maps were created from aerial photography and photo-revised in the 1960s.[1] Once digitized, wetland data were then compared to more recently acquired data.

KPWS and YDNP represent opposite ends of the extant Central Indochina Dry Forest Ecosystem (fig. 3.2). Deciduous *Dipterocarp* forests are found in the more arid areas of the Mekong Basin on well-drained soils and form open canopy woodlands with varying density of trees that collectively compose the Central Indochina Dry Forest Ecosystem (Rundel 2009). Extensive deciduous *Dipterocarp* forest has been cleared in Thailand, Lao PDR, and Vietnam (Baltzer et al. 2001). KPWS is located within the

Figure 3.2. Study areas in Cambodia (Kulen Promtep Wildlife Sanctuary, KPWS) and Vietnam (Yok Don National Park, YDNP) with primary vegetation communities depicted as a base layer. Note that both conservation areas are dominated by deciduous *Dipterocarp* forest and occur at the western (KPWS) and eastern (YDNP) extent of this ecosystem.

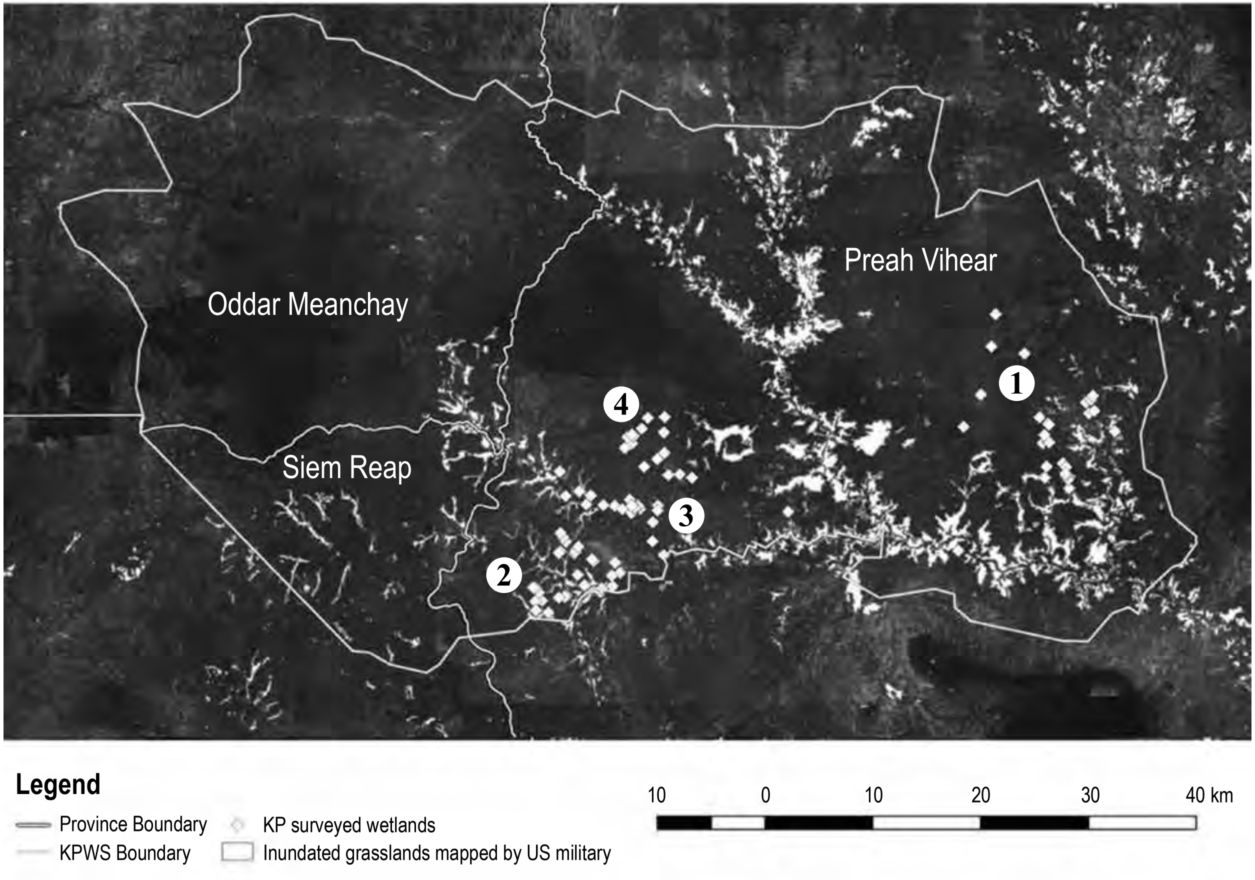


Northern Plains of Cambodia and straddles Preah Vihear, Siem Reap and Oddar Meanchey provinces (fig. 3.3). KPWS is managed by the Ministry of Environment (MoE). Within KPWS, visited wet sites were located near four villages (Tmat Bouy, Rum Chek, Sambour and Prey Veng), all located within Preah Vihear province (fig. 3.3). Based on information gathered through interviews with village leaders, researchers chose wet sites to visit. Target wet areas reflected a diversity of potential wetland types, sizes and distances from each village. Likewise, YDNP is located in the Central Highlands and the Srepok River, an important tributary of the Mekong River, passes through the park. As with KPWS, YDNP is mostly covered by deciduous *Dipterocarp* forest (Baltzer et al. 2001) and contains numerous potential wetlands (fig. 3.2). Wet areas visited were based on information provided by a previous study (Nguyen et al. 2004) and varied like Cambodian wet areas that were selected.

Wetland form, hydrology and soil

During visits to each wet area researchers measured width, length, circumference (using GPS), water depth and hydrological features (e.g. channels). To ground truth historical data, location, shape and size for wet areas were measured on the ground and compared to historical military map data. The profile of each wet area was categorized as one of four types (basin, *baray*/frying pan, flat, oxbow/channel) based on assessment in the field or provided by interviews with villagers familiar with the region. Three soil profiles were collected from each wet area visited in January 2016, using a soil auger. Soil profiles were located at the deepest part of the wet area (usually the center), at the edge of the wet area where the plant community transitioned between inundated and dry areas, and half-way between these two points. The purpose of the soil profile was to examine color, biological activity, texture and moisture content of different soil strata which would characterize the formation, disturbance and weathering of soil layers in the primary soils from the basin and the amount of drying that occurred within these soils on a decadal timescale (Tran et al. 2014; Soil Science Division Staff 2017).

Figure 3.3. Palustrine wetlands from US military maps (white) and plotted locations of ground survey areas (white diamonds) for Kulen Promtep Wildlife Sanctuary, Cambodia. The background layer is composed of aerial images from Google Map and villages that the team visited are labeled 1=Tmat Buoy, 2=Rum Chek, 3=Sambour and 4=Prey Veng.



Wetland biota and human use

Researchers collected two kinds of plant data: presence/absence of all plant species found in each wet area and aerial coverage data for the dominant species located in wet areas surveyed during 2016. Plants were photographed and voucher specimens were collected for species identification and herbarium preservation. Where soil profiles were studied, quadrats were used to compare vegetation dominance to water permanence as interpreted through soils data.

Different active gears were used to sample each wet area for fish where water was found. Following Ainsley et al. (2018), backpack electrofishing was used for 2–10 minutes, depending on the size of the water pool. In shallow wetlands the electrofishing team (one person with backpack and one person with net) covered as much of the open water area as possible. Deeper wetlands were sampled only from the shoreline to 0.75 m of water. Where enough water occurred, a seine (0.64 cm mesh, 1.2 m high and 3.7 m long) was used to sweep three times, each time in a different spot for each site. When water was deeper than 0.5 m, and time allowed, gill nets (mesh sizes 1.5 cm and 1.25 cm) were deployed and baited minnow traps were placed and checked after 30 minutes. Fish were collected live, identified to species (Rainboth 1996; Vidthayanon 2008), counted and, unless preserved for identification, released.

Bird species were recorded at all visited wetlands and identification was determined by sight or sound (Robson 2000; www.xeno-canto.org, accessed Sept. 4, 2017). Quantitative bird data followed the Standardized North American Marsh Bird Monitoring Protocols (Conway 2009). The method was designed for a 1-hour point count conducted concurrently at a selected wet area and an upland forest site located 400 m from the selected wet area.

For socioeconomic data people were interviewed in villages found near study wetlands (Sok 2017). Sixteen percent of the households in each of two villages were randomly selected for interviewing (Tmat Buoy and Rum Chek; fig. 3.3) and questions related to income, food, material or medicine obtained by people from wet areas were posed. Key informants such as government officials at MoE, KPWS staff, community leaders and village chiefs were also interviewed. With key informants questions focused upon issues related to wetland resource use, wetland management and policies. No interviews were conducted in Vietnam due to government restrictions. Ad hoc interviews of people living in Tmat Buoy and Rum Chek were also conducted in 2015 by fish biologists to assess human use of the fish resources located near the villages.

Results

Wetland shape, hydrology and soil

Out of 110 site visits at KPWS and 70 site visits at YDNP, 97 and 48 unique wet areas respectively (total=145) were surveyed from 2014 to 2016. Surveys occurred May-June and October during the rainy season and January during the dry season. Some wet areas were visited in both seasons. Samples for soils and birds were only measured in January 2016 and included 30 wetlands at KPWS and 31 wetlands at YDNP. Collectively, surveyed sites in both conservation areas spanned a wide

Table 3.1. Characteristics of wetlands sampled at Kulen Promtep Wildlife Sanctuary (KPWS), Cambodia and at Yok Don National Park (YDNP), Vietnam 2014–2016

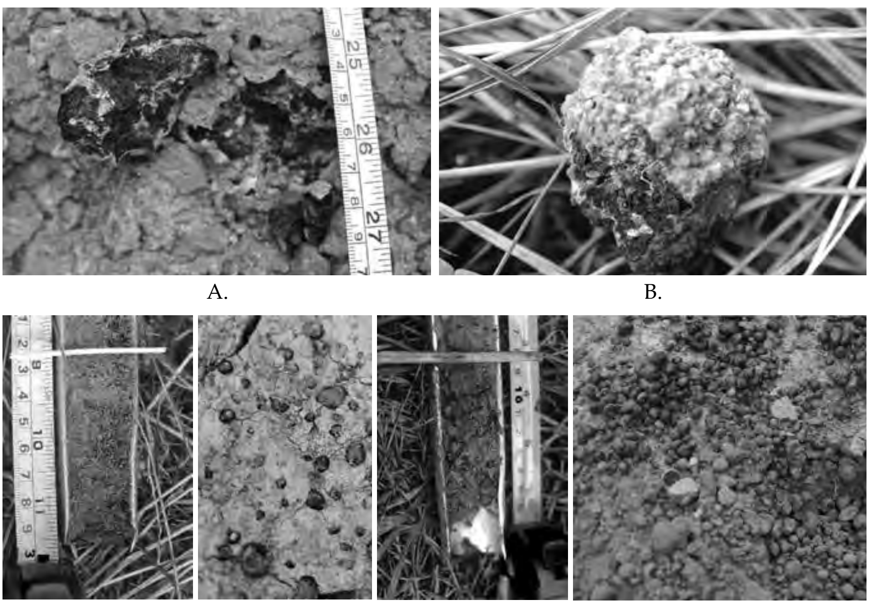
	Conservation Area	
	KPWS	YDNP
No. of Wetlands	91	48
Wetland Size (ha)		
Average	31.2	0.9
Median	0.2	0.03
Min.	0.0005	0.004
Max.	75.9	21.0
Standard Deviation	12.5	3.2
Hydrology		
Connected to Stream (%)	15	7
Isolated (%)	85	93
% Wetlands with Basin Profile		
Isolated River Channel	1	
Flat	30	16
Frying Pan	4	
Shallow basin	65	84

Note: Though 97 unique wetlands were studied, only 60 basins had their perimeters mapped to calculate wetland area and 91 basins were measured for hydrology and profile.

range of sizes, hydrology and geomorphology so that ground surveys could be compared to historical data from US military maps. Generally KPWS wet areas were larger, more hydrologically connected and flatter in profile than wet areas found at YDNP (table 3.1). Beyond connection to channelized flow it was not possible to assess hydrological connectivity in the rapid surveys. Profiles at KPWS included basins (shallow bowls), frying pan-shaped basins (which were flat basins with steep edges called *barays*), channels (e.g. oxbows), and flat areas. Frying pan basins were often man-made (see wetland disturbance) and did not occur at YDNP.

In 2016, 194 soil layers from 90 soil profiles of 30 sites were measured at KPWS, and 128 soil layers from 93 soil profiles of 31 sites were measured at YDNP. For both sites the top 8–10 cm layer of all soil profiles

Figure 3.4. Common laterite (a) and biological laterite (b) are formed from different processes: common laterite is subjected to normal weatherization whereas biological laterite is subjected to development from soil insects and fire. Laterization, in turn, helps identify origin and function of wetland soils where man-made wetlands lack laterite gravel because it has been removed (c), or animal disturbance has caused gravel to be redistributed along the soil profile (d) and where natural wetlands contain un-disturbed laterite gravel layers beneath surface soils (e and f). All photos by Duong Van Ni.



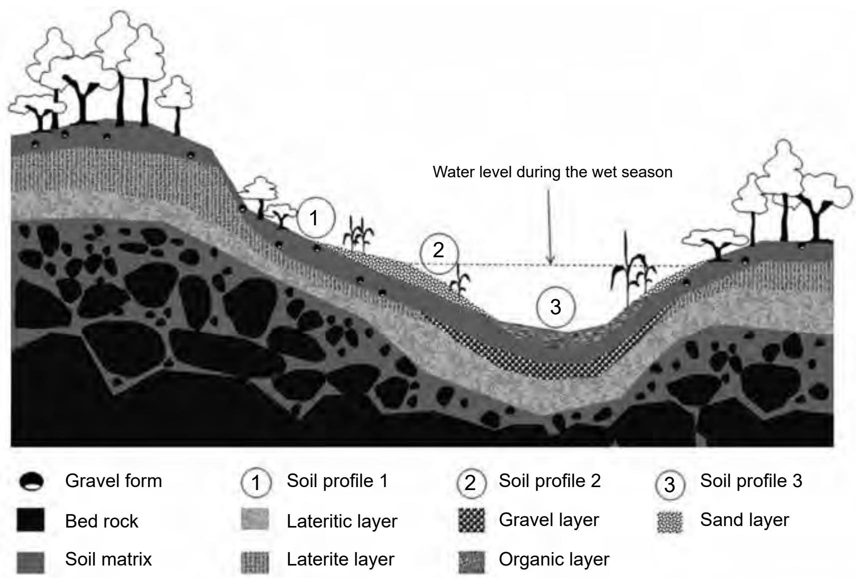
A. B.

C. D. E. F.

was composed of reduced, organic material that was mixed with clay or silt and was typical of anaerobic conditions found in soils because the presence of water prevents oxidation. The second layer of the soil profile (at least 10–20 cm below the soil surface) was either composed of laterite gravel or, if missing gravel, was composed of clay. When present, the gravel layer extended down to 60 cm below the soil surface and was either concentrated so thickly that a soil auger could not penetrate this layer or the gravel was mixed with clay. Both the gravel and clay profile layer indicated anaerobic conditions. When present, soils within the third layer below the soil surface were composed of clay and were highly oxidized indicating earlier, drier conditions.

Laterization is one of the main soil formation processes occurring in all soils found at both study areas and the process for how laterite gravel layers were distributed in various soils appeared key in determining wetland origin. Lateritic soils occurred from two distinct processes: one driven by normal weatherization (fig. 3.4a) and one by animal activities

Figure 3.5. A generalized cross-section of a basin profile, describing typical soil layers in relation to wetland formation and function, in the Central Indochina Dry Forest Ecosystem. Soil profiles, upon which this diagram is based, were collected at the wetland edge (1), center (3) and between the edge and center (2). Slopes in the figure are exaggerated to illustrate the soils and hydrology.

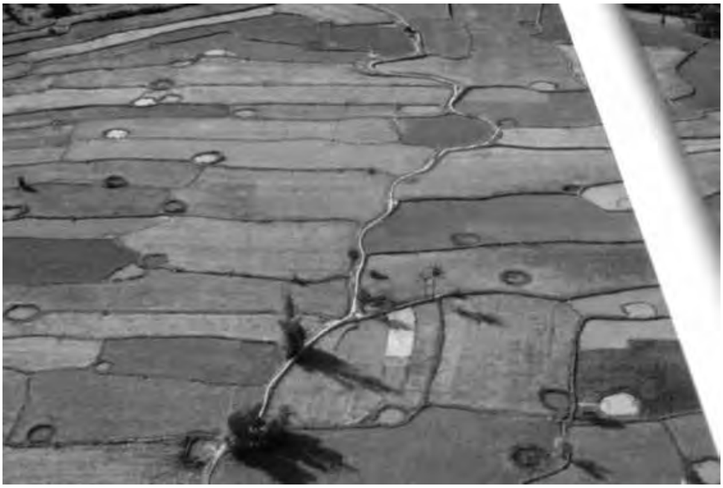


(e.g. termites; fig. 3.4b) in conjunction with frequent fires. Both processes involved strong oxidation. Laterite gravel was diffusely distributed in upland soils 8–10 cm beneath the soil surface, but the layer of gravel was more concentrated, and found primarily in the second soil layer down in wet areas, not in the first layer as in upland (non-wet) soils (fig. 3.5).

Within wet areas, and based on the presence as well as distribution of laterite gravel in the soil profiles, levels of soil disturbance was inferred. Natural, undisturbed wet sites in this study often had a dense layer of laterite gravel deposited beneath an undisturbed, anaerobic, sedimentary layer composed of clay or silt (figs. 3.4e and 3.4f). The laterite gravel had likely accumulated through wind and water erosion that moved laterite gravel from adjacent upland areas to wet basins. Natural wet areas that were disturbed by animal activities, such as by elephants (*Elephas maximus*) or cattle (*Bos taurus*), often had laterite gravel redistributed along the vertical profile and were mixed with sedimentary depositions throughout as much as 50 cm of the second profile layer below the soil surface (fig. 3.4d). No dense layer of gravel in these wet areas was present. For wide layers of gravel mixed with sediment (i.e. 20–40 cm) animal disturbance would have occurred over centuries. In contrast, laterite gravel layers were completely absent from man-made wet areas, presumably because this layer was physically removed (fig. 3.4c). In man-made wet areas the first soil layer in the profile was still composed of anaerobic organic materials and silt or clay, but the second layer was composed of only clay. Wet area soils with missing gravel layers were found in the barays of Prey Veng and Pring Thom of KPWS. Bomb craters might be typified by a similar removal of the gravel layer but the basin would be a deep, relatively narrow basin and have a uniform, round perimeter (fig. 3.6)—contrasting greatly with the rather deep, rectangular frying pan basin as found in the barays. Deep anaerobic soils would also be absent from the bottoms of bomb craters since oxygen depletion in these basins would have been relatively recent (since the 1960s or 1970s). More recent human excavations could be shaped like bomb craters and it was not possible to distinguish human excavation from bomb craters by soil profiles alone.

Laterite gravel may also help determine the duration of water permanence in wetlands during the dry season. The laterite gravel was concentrated in the bottom of natural wetlands where no other laterite

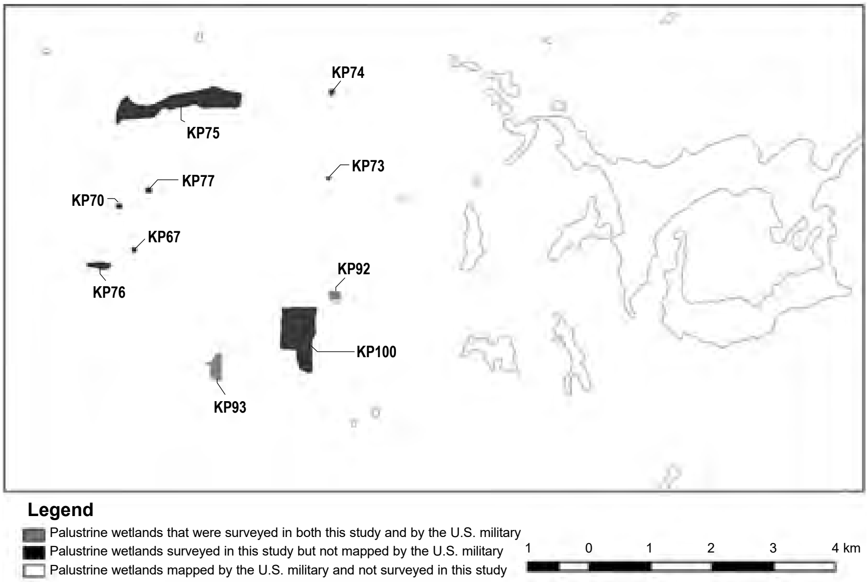
Figure 3.6. Bomb craters from the Vietnam War located in paddies of southern Lao PDR. Note the uniform appearance of perimeters of each crater. Photo taken on August 16, 1996 by Jeb Barzen.



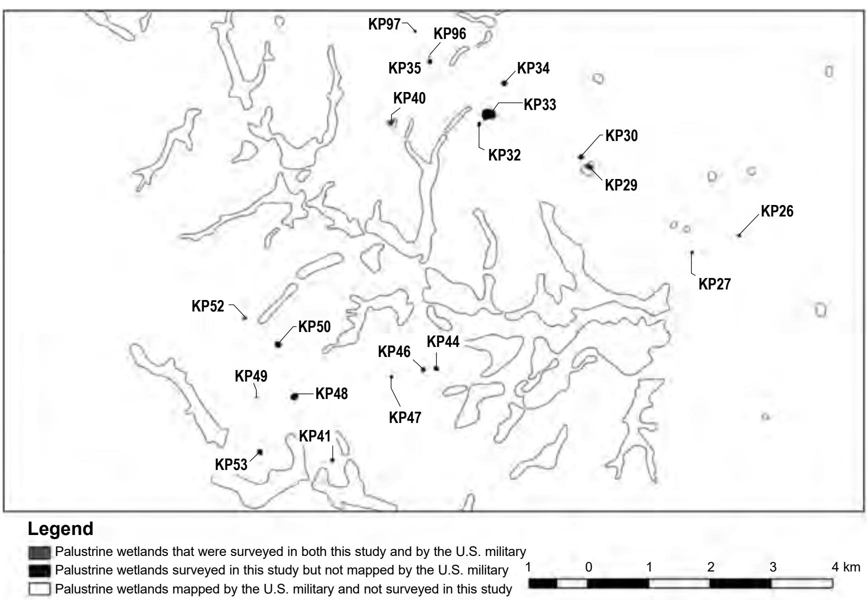
layer existed because of anaerobic conditions. The gravel was connected to the sub-surface layer of oxidized laterite underlying upland soils located next to wet sites and laterite soil has high hydrological connectivity. Water entering the upland soil thus percolates down to the laterite layer and then moves more rapidly horizontally once it meets the relatively impermeable lateritic layer, eventually reaching the gravel layer in the basin (fig. 3.5). This more rapid ground water discharge into wet areas could increase the length of the inundation period.

Finally, sites surveyed 2014–2016 were compared with historical wetland locations derived from the US military maps: 12 of 145 wet areas surveyed for this study (8 percent) were located on US military maps (9 wetlands in KPWS, figs. 3.7a–d; and 3 wetlands in YDNP; fig. 3.8). Historical wetlands tended to be larger than surveyed sites but both estimates retained largely the same position and shape. The difference in basin size between historical and surveyed wetlands could be due to how much water was in the basin at the time each site was examined. Most of the inundated grasslands of the military maps (to the right on fig. 3.7a and b, to the left on figs. 3.7 c and d) were in floodplains of small streams so the amount of water held within the basin could be highly variable (see discussion under vegetation section).

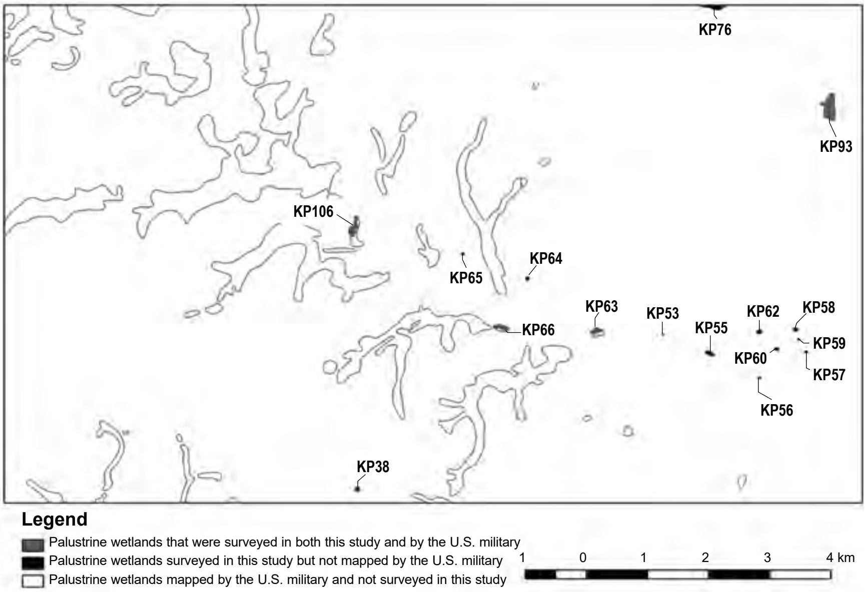
Figure 3.7. Palustrine wetlands located within Kulen Promtep Wildlife Sanctuary (Cambodia) near villages of a) Prey Veng, b) Rum Chek, c) Sambour, and d) Tmat Buoy that were mapped by the US military (white with grey outline), surveyed on the ground (black), or were evaluated by both efforts (grey). KP# refers to the wetland ID generated during the ground survey.



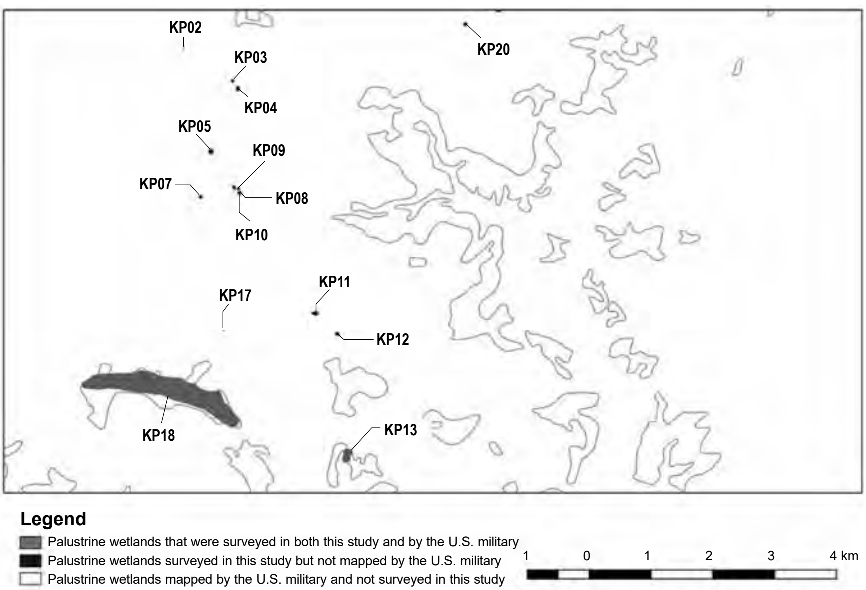
A. Prey Veng



B. Rum Chek

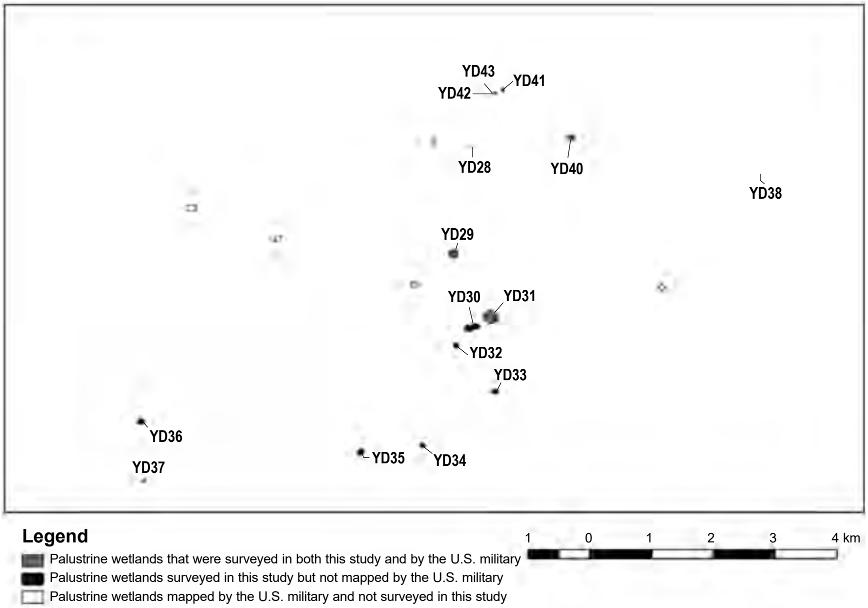


C. Sambour



D. Tmat Buoy

Figure 3.8. Palustrine wetlands located within Yok Don National Park, Vietnam, that were mapped by the US military (white with grey outlines), surveyed on the ground (black), or were evaluated by both efforts (grey). YD# refers to the wetland i.d. generated during the ground survey.



Importantly, 133 of 145 wet areas (92 percent) were surveyed but were not mapped by the US military. Wet areas that were not mapped historically tended to be smaller than historical wetlands (figs. 3.7c, d), but large wet areas were also missed by the historical wetland maps (e.g. KP33, KP75, KP76, KP100; figs. 3.7a and b). Surveyed wet areas that were not mapped by the US military may have been too small to detect on aerial images or, though detectable, these wetlands may have been considered insignificant to map for military purposes. Because target wet areas were identified through interviews with local residents, it was not possible to estimate the number of historical wetlands that were mapped which, upon ground survey, were not actually wetlands (Type II error, Sokal and Rolf 1981).

Wetland flora

A minimum of 110 plant species were found in 145 sites (97 in KPWS and 48 in YDNP) and 61 of these wet areas were sampled for vegetation dominance (30 from KPWS and 31 from YDNP). The vegetation of hydrologically isolated wet areas with basin topography (*Trapaeng* in Khmer and *Bàu* in Vietnamese) showed clear zonation where plant community composition changed in relation to water depth (thus length of inundation period) and soil characteristics. Usually, basin profile wet areas had a center that was the lowest elevation and therefore held water for the longest time or, in deeper wetlands, contained standing water all year round. Moving out from the basin center, the soil elevation increased and water became shallower so inundation times decreased and plant composition reflected shorter inundation times. The third vegetation zone occurred in relatively high areas near the beginning of upland (usually forested) vegetation (fig. 3.9).

Figure 3.9. Typical palustrine wetland basin in the deciduous Dipterocarp forest. Note the abrupt transition from upland forest to wetland vegetation and then the zonation between areas typical of moderate inundation times around the wetland edge compared to deeper water areas in the wetland center. Photo by Tran Triet.

In both KPWS and YDNP the center (deepest) zone was often occupied by aquatic plants that preferred permanent water or prolonged wet conditions. Common plants that were found at the center zone: *Actinoscirpus grossus*, *Oryza rufipogon* (wild rice), *Cyperus digitatus*, *Cyperus* *compactus*, *Nelumbo nucifera* (lotus), *Utricularia aurea* (bladderwort), *Coix aquatica*, *Ipomoea aquatica* (water morning glory) and *Eleocharis acicularis* (spike rush).[2]

The middle zone was covered by plant species that tolerated intermediate inundation such as: *Eragrostis aspera* (love grass), *Ischaemum rugosum*, *Fimbristylis quinquangularis*, *Panicum repens* (torpedo grass), *Axonopus compressus*, *Paspalum* sp. (bead grass), and *Eriocaulon henryanum* (pipewort). Towards the basin edge, where inundation times were shortest, plant species included: *Imperata cylindrica* (cogon grass), *Arundinaria* sp., *Scleria ciliaris*, *Pennisetum polystachyons*, *Cheliocostus speciosus*, *Hyptis* sp., *Osbeckia sinensis*, *Pogostemon stellatus*, *Hediotis* sp., and *Streptocaulon* sp. Some plant species of the basin edge grew in upland environments but were not as common there as they were in the basin edge zone. The edge zone was also characterized by the presence of woody trees and shrubs: *Syzigyum* sp., *Gmelina* sp., *Vitex* sp., *Zizyphus* sp., and *Dillenia hookeri*.

In addition to wet areas with a basin, frying-pan and channel profiles, sites that were larger (>10 ha) were encountered and these wet areas were dominated by grasses among scattered trees and had a flat topography. These large, flat sites, *veal* in Khmer and *trãng* in Vietnamese, still contained reduced soils (the center and middle profiles of Veal Pong [75.9 ha] had color codes of seven in all layers), but had inundation times, soils and plant species similar to the edge and intermediate zone of basin type wet areas. Though plant species found in veals were similar to those found in the intermediate and edge zones of basin wet areas these communities were much larger in flat wet sites than in basin wet sites.

Wet areas in KPWS constructed during the Angkor era tended to have large vegetation zones like veals but the vegetation zones were more typical of moderate to deep zones of inundation because the depth of the basin was approximately 1–2 m versus 0.2–0.5 m in veals. Regardless of site profile, most of the plant species found in wet areas were typical of wetland vegetation and atypical of adjacent upland vegetation. Profiles of wet areas found in YDNP were either basin or flat and the flat profiles were much smaller than Cambodian veals (table 3.1). Plant species found in the different vegetation zones for both KPWS and YDNP, however, did not differ substantially.

Wetland fauna

Fish were surveyed in a subset of the 145 wet areas visited. At KPWS fish were sampled at 41 sites during the early wet (May/June, 2015; *n*=5), wet (October, 2015; *n*=13) and dry (January, 2016; *n*=23) seasons, and the percentage of sampled sites that were occupied by fish varied at 80 percent, 92 percent, and 87 percent, respectively. In YDNP, fish sampling was conducted in 18 wet areas during the early wet season (May 2015), and fish were found in 22 percent of these areas.

A total of 53 fish species were collected from wet areas of KPWS and seven species from YDNP. Since YDNP was only sampled in May, 2015, when the majority of wet sites were dry (i.e., no pool of standing water), most analyses were performed with data from KPWS. Compared to 53 fish species of fish sampled in KPWS, 80 species were reported by villagers in Tmat Buoy and Rum Chek villages through ad hoc interviews focused on fish resources. Species richness was calculated as the total number of species identified in the combined fish catch for active sampling methods at each site when fish were present. At KPWS, species richness for each wet area ranged from 1 to 12 species (average=6.25) during the early wet season, 2 to 15 species (average=7.50) in the late wet season and 1 to 15 species (average=5.40) in the dry season. The maximum species richness for wet areas studied at YDNP was five species in the early wet season.

In YDNP, the seven fish species found were *Anabas testudineus* (climbing perch), *Channa striata* (striped snakehead), *Clarias batrachus* (walking catfish), *Pristolepis fasciata* (Malayan leaffish), *Rasbora borapetensis* (red-tailed rasbora), *R. paviana* (sidestripe rasbora), and *Trichopodus trichopterus* (three spot gourami). At KPWS, the most frequently collected species were *R. paviana*, *A. testudineus*, *Esomus metallicus* (striped flying barb), *Trichopsis vittata* (croaking gourami) and *T. trichopterus* (see Ainsley et al. 2018 for more detail). One species considered rare in Cambodia, *Puntigrus partipentazona* (partipentazona barb), was sampled as was one species considered as near-threatened (*Clarias macrocephalus*) and one species considered vulnerable (*Oxygaster pointoni*) on the IUCN Red List.[3] *Trichopodus trichopterus* was the most frequently encountered species for all seasons in KPWS, composing 22.3 percent of all individuals captured. Where only one species was found in a wetland, that species was either *A. testudineus* or *Clarias batrachus* (in YDNP only), both of which are tolerant of poor water quality conditions. Upon examination of how the characteristics of wet areas might explain patterns of fish occurrence, no significant correlation between log-transformed wetland area (m^2) and log-transformed species richness or Shannon-Weiner diversity index was found. There was a significant, positive correlation between maximum water depth and species richness, as well as between maximum depth and Shannon-Weiner diversity. Water depth, in turn, was influenced by wet area profile. Wet area fish assemblages did not differ based on connectivity, but sites closer together were more similar, indicating that wetland assemblages were different throughout KPWS and may not form a single natural management unit. Conserving a large variety of small scattered (rather than clustered) wetlands may be required to adequately represent the fish species diversity located within any single protected area.

A total of 130 bird species were recorded during surveys (123 species at KPWS and 96 species at YDNP). Compared to jackknife estimates (Krebs 1999) of the total number of species in the avifauna available during the survey at KPWS and YDNP (147±17 and 110±4 species respectively), 84 percent and 87 percent of the bird species likely to be seen at KPWS and YDNP respectively were found. In KPWS, higher bird diversity was observed at wet sites versus adjacent uplands: 105 bird species in wet areas and 74 species in nearby forest habitats. Bird species richness in YDNP, however, was similar between wet areas and upland forests (80 species at wet sites and 82 species at upland forests). Even so, wet area species were seldom encountered in upland forest areas whereas forest species were often encountered in or near wet areas. This pattern of species richness may correspond to the relative sizes of wet sites in the two conservation areas. Most wet areas in YDNP were smaller than those surveyed in KPWS (table 3.1), so forest birds would more easily be seen near the wet sites surveyed in YDNP.

One of the most frequently recorded bird species in the survey was the Eastern Spotted Dove (*Spilopelia chinensis*) for which 183 individuals were seen in 69 sample plots. Although this species is considered a "forest bird" in the dichotomous definition of wet area vs. forest, it was found more often in or near wet habitats: 37 times in wet area compared to 28 times in forests. The most common wetland bird species was the Chinese Pond-Heron (*Ardeola bacchus*) which was observed 22 times in wet areas and twice in upland forests. The second most common wetland species was the White-breasted Waterhen (*Amaurornis phoenicurus*) which was only found in wet areas. Wet areas, therefore, provided habitat for forest birds as well as for wetland species but wetland species were rarely found in upland areas. Twelve globally threatened bird species, half of which are wetland species, were listed in IUCN's Red List[4] and were recorded in this research (table 3.2).

Table 3.2. Twelve bird species of conservation concern found at Kulen Promtep Wildlife Sanctuary (KPWS) and Yok Don National Park (YDNP) in relation to their frequency of observation in 2016 and their primary preferred habitat (wetland or forest). IUCN's Red List category: NT - Near Threatened; VU – Vulnerable; CR – Critically endangered.

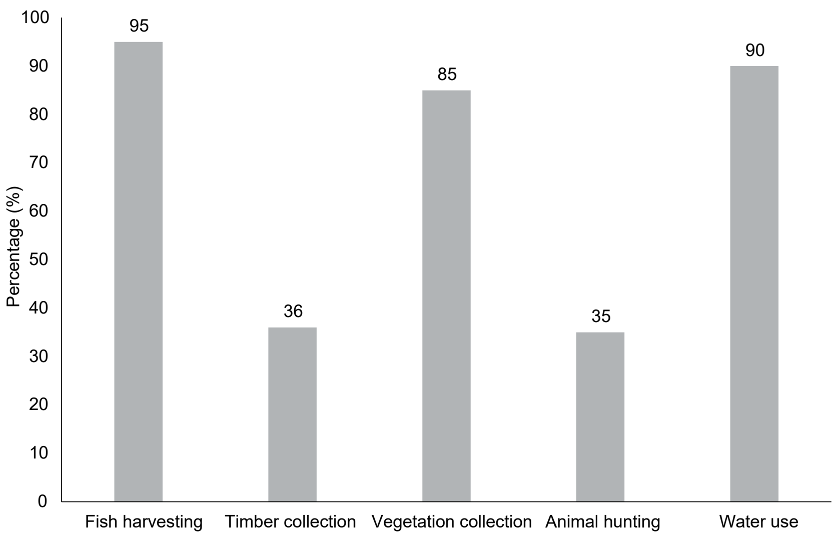
English name	KPWS Frequency	YDNP Frequency	IUCN Category	Primary Habitat
Blossom-headed Parakeet	18	13	NT	Forest
Grey-headed Fish-eagle	1	0	NT	Forest
Grey-headed Parakeet	0	2	NT	Forest
Great Slaty Woodpecker	4	2	VU	Forest
Lesser Adjutant	5	5	VU	Wetland
Oriental Darter	1	0	NT	Wetland
Red-breasted Parakeet	33	25	NT	Forest
White-rumped Pygmy-falcon	1	0	NT	Forest
Asian Woollyneck	0	4	VU	Wetland
Sarus Crane	7	0	VU	Wetland
White-shouldered Ibis	1	0	CR	Wetland
Giant Ibis	1	0	CR	Wetland

Notes: Frequency was measured by the number of times this species was encountered during our surveys at this location.

Human use of wetlands

Interviews were conducted at 54 households of Tmat Bouy and 30 households in Rum Chek villages during March, 2016. A total of 84 people, 60 men and 24 women, were interviewed. More men were interviewed because men in the villages utilized the forests more often and therefore had more information about wet areas. Most informants had only primary education (53.5 percent) while 8.5 percent had high school education. Ninety-five percent of informants said farming provided their main source of income for their family with rice being the most important crop, followed by cassava and vegetables. Yet 64 percent of informants said they received other sources of income besides farming. Most common income-generating activities were fishing, hunting, gathering forest products, transportation and merchandising (small shops). Importantly, most households gathered resources from wet areas, primarily through fishing, gathering vegetation (for both food and weaving) and for water (fig. 3.10). People collected 16 fish species for household consumption and 97.5 percent of all fish caught were consumed by households. Only one species of fish was caught and sold in the market, *Anabas testudineus*, which was a common species collected during the surveys. Though fish resources were known and used by people in the villages, the understanding of fish conservation was limited and resulted in the use of many illegal capture techniques. Water consumption was mostly related to household use. Accordingly, most interviewed people (99 percent) could recognize wet areas and thought wet areas were important for their livelihoods. Three of four villages participated in community conservation programs that focused on forest and wet area protection for resource use and tourism. Local people harvested many kinds of wet area and forest products: *Dipterocarp* tree resin, fish, crabs, eels, shrimps, frogs, snails, water lilies, bamboo shoots, and plants used for weaving.

Figure 3.10. Frequency of household uses for resources gathered from palustrine wetlands in Kulen Promtep Wildlife Sanctuary



According to interviews, population growth in villages located within KPWS has resulted in farmland expansion for rice growing that may threaten wet areas if use is too intensive. Land concessions, mostly for rubber plantations, are another important cause of forest loss that villagers identified, including the loss of wet areas located in these forests. Rice paddy expansion, however, most directly involved wet areas because these sites were easier to convert and wet area soils were more suitable for growing rice.

For wet area management, people in three visited communities have established a forestry community to protect wet areas from illegal activities. The fourth village, Rum Chek, was processing legal documents to establish a forestry community at the time of the study. Interviewees thought that management of wet areas was insufficient due to the lack of logistical support from the KPWS, financial support, and technical assistance. Interviewees also identified that they lack means to protect small wet areas in the dry open Dipterocarp Forest community. Local attitudes identified a high value placed on resources provided by wet areas including water availability, fish species diversity, birds and surrounding big tree wet areas that attract tourists.

Discussion

The first goal of this study was to determine whether palustrine wetlands existed by asking: Are depressions in the deciduous *Dipterocarp* forest true wetlands or are they simply areas of forest that accumulate water during the rainy season? If true wetlands, numerous questions follow: What distinguishes them? Where can they be found? How do people use them? What are the threats that they face? and What is their conservation status?

Data from this study suggest that the water bodies examined were clearly palustrine wetland ecosystems. Basin profiles allowed longer inundation periods, soils reflected anaerobic conditions due to water saturation, plant species were primarily aquatic and occurred in zones typical of wetlands, fish were prevalent during inundation periods, and aquatic birds utilized these ecosystems while mostly avoiding upland areas. Basin profiles alone, however, may not be capable of creating inundation periods long enough to support the high diversity of aquatic organisms that were found. Wetland formation may be driven by both basin shape and soil type through a more complicated geomorphological formation as a precursor to wetland establishment. First, within surface depressions of varying degrees, laterite gravel was concentrated from wind and water movement but remained connected to laterite soil layers found in upland areas, allowing ground water movement to be directed towards depressions. The impermeable lateritic layer, subtending the laterite layer, forms a barrier to further downward movement of water, acting as an aquitard beneath the wetland basin. Second, sub-surface hydrological connectivity, in turn, increases inundation length during the dry season by providing groundwater flow into basins which was key to providing sufficient development periods for aquatic plants and animals. Third, with extended inundation, organic material, clay and silt accumulated at soil surfaces that then developed wetland soils.

Conservation implications

Though the contribution to biological diversity by wetlands in the deciduous Dipterocarp forest has not been studied greatly (Keo 2008, Wright et al. 2010), the diversity of the deciduous Dipterocarp forest in general has been recognized (Baltzer et al. 2001, Rundel 2009). Palustrine wetlands located within this forest ecosystem are hypothesized to drive much of that diversity through provision of unique habitats for aquatic flora and fauna, but also through provision of ephemeral habitats for species that are normally considered upland species. The function of wetlands as dry season watering holes for large terrestrial mammals (Gray et al. 2015), exemplify this role.

Disturbance of wetlands has occurred in a variety of forms within both conservation areas (table 3.3). Use of wetlands by large mammals has occurred for centuries, as indicated by the extensive layer of reduced materials mixed with the laterite gravel that was found in many wetlands. Likewise, long-term human disturbance was apparent at KPWS, but not at YDNP. Angkor-era *barays* were built for religious and perhaps agricultural purposes, but also to remove lateritic soils for building materials (Tardy 1997). More recent human disturbance of wetland basins was also evident and could be due to detonation of bombs or to soil excavation. Though the soil profiles offered little evidence that could be used to distinguish between bombs and recent human excavation, shapes of bomb craters would typically be round and examined wetlands were not uniformly shaped, so bombs were not thought to be a cause of many wetland formations. In addition, excavation of wetlands for agricultural (this study) or for conservation purposes (Gray et al. 2015) has been common, especially in YDNP (Le and Eames 2003).

Table 3.3. Evidence of wetland disturbance, based on soil profiles, at Kulen Promtep Wildlife Sanctuary (KPWS), Cambodia and Yok Don National Park (YDNP), Vietnam 2016

Conservation Area	Wetland Disturbance				
	# Wetlands	Un-disturbed	Animal	Human - Angkor Era	Human - Modern Era
KPWS	30	8	8	2	12
YDNP	31	2	5		24

Depending on their location, palustrine wetlands may be influenced by water infrastructure development and water use further upstream. The distribution of basin wetlands in KPWS appears correlated with the upper drainage areas for watersheds of secondary and tertiary river systems while flat basin wetlands appear to coincide with middle reaches of these same watersheds (figs. 3.3, 3.11). In contrast, basin and flat palustrine wetlands at YDNP were clearly removed from the Srepok River or smaller streams but did not appear correlated with specific watersheds (fig. 3.11). Further studies investigating the connection between these watersheds and the palustrine wetland ecosystems would inform future assessments of the effects of water resource development.

Considerable effort has been committed to conserve some palustrine wetlands, especially in KPWS, but these actions are not effective for all species (Keo et al. 2009; Clements et al. 2013; Gray et al. 2015; Clements and Milner-Gulland 2016). Declines in at least some waterbird species, such as the Eastern Sarus Crane (*Antigone antigone sharpii*), continue and appear related to loss of wetland ecosystems (Van Zalinge, unpublished data). In this study most veals, for example, have been converted to rice paddy. Human uses of wetland resources is still extensive (Sok 2017), and the use of wetlands by people constitutes both a threat and an opportunity (Clements and Milner-Gulland 2016; Barzen 2018). A large proportion of wetlands still exist outside of conservation areas as well (fig. 3.11).

An objective of this study was to provide information for decision-makers to understand potential impacts of development projects and land-use changes; thus, an important outcome of this study was estimating the spatial extent of these wetlands. The sampled wetlands from this study were not only determined to be palustrine wetland ecosystems, but these ecosystems were related to wetlands mapped decades ago by the US military. Though not created for conservation purposes, historical military maps are the only existing dataset that illustrate wetland distribution on a landscape scale in Southeast Asia and are, therefore, of great importance to the future conservation of wetland ecosystems and the associated dry forest.

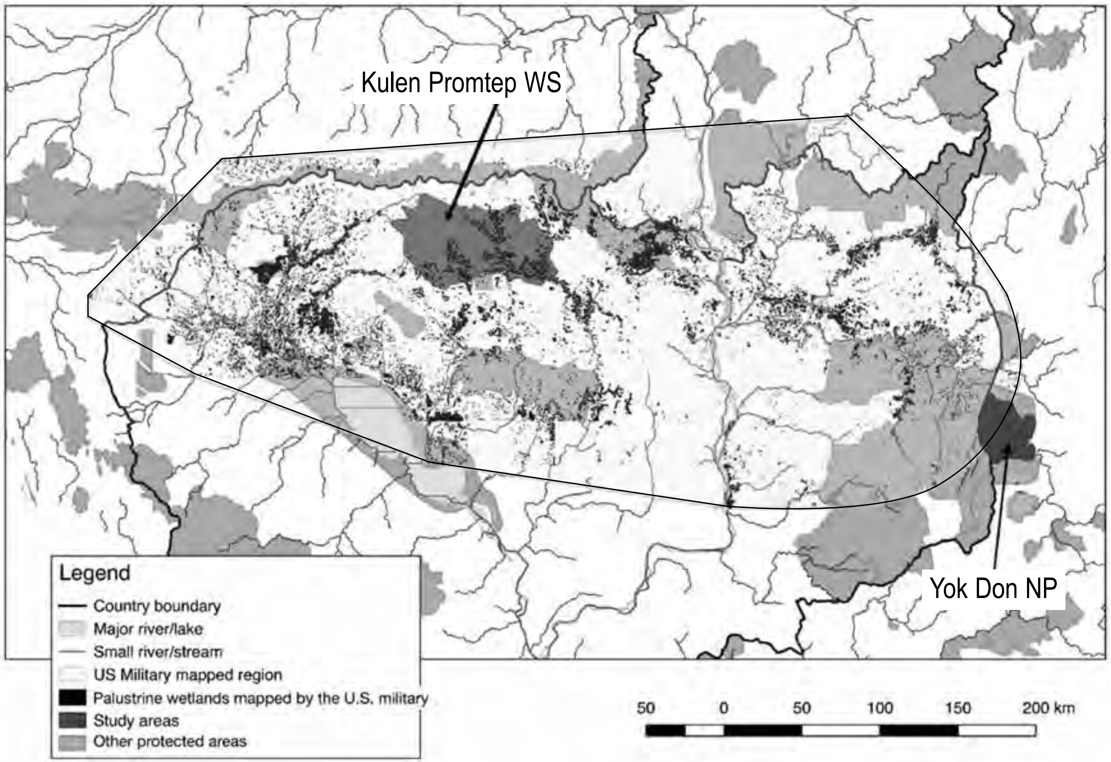
Digitized wetlands from these military maps in northern Cambodia, far southern parts of Lao PDR, northeastern Thailand and far western Vietnam, depicted numerous wetlands and these wetlands were often associated with river systems as found in KPWS (fig. 3.11). Importantly, this study found many wetlands, primarily smaller basins, that were not mapped by the military. The estimate of wetland coverage on military maps is, therefore, likely an underestimate of the total number of palustrine wetlands that are scattered throughout the deciduous *Dipterocarp* forest. Barzen (2004) also found numerous wetlands using military maps and used them to locate large waterbirds throughout the region in Cambodia, providing further evidence that potential areas mapped by the US military located outside of KPWS and YDNP were also palustrine wetlands and important areas of biological diversity.

Though small and numerous, failure to recognize and fully map palustrine wetlands is a primary barrier to protecting these important ecosystems. Wetland data contained within historical military maps form a foundation from which wetland conservation can quickly advance. Certainly, further work is urgently needed to update these maps in Cambodia and then assess losses that have occurred from the 1950s until now. Similar work can be completed in southern Lao PDR, northeastern Thailand and western Vietnam.

Recommendations for future conservation

Water bodies scattered in the deciduous Dipterocarp forest are palustrine wetland ecosystems that lay within the Central Indochina Dry Forest Ecosystem and contribute significantly to the biological diversity for which this ecosystem is known. Having hydrology, soils, plants and fauna that are typical of wetland systems, palustrine wetlands meet the many definitions proposed for wetland systems (Mitsch and Gosselink 2015).

Figure 3.11. Palustrine wetlands (black) mapped by the US military from the late 1950s to 1970 in northern Cambodia and small parts of Lao PDR, Thailand, and Vietnam. Conservation areas are in light grey and the two study areas (Kulen Promtep Wildlife Sanctuary and Yok Don National Park) for this project are darker grey.



Both within and between palustrine wetlands, there is great variation in geomorphology, water inundation periods, soil characteristics, plant community composition and faunal use which supported a large collective biological diversity and ecological function even though any one wetland, because it was relatively small, was less diverse. Historically, palustrine wetlands were estimated at 18,911 individual wetlands within a large portion of the Central Indochina Dry Forest Ecosystem (Barzen 2004) but, due to the omission of many smaller wetlands, this total may exceed 20,000 wetlands. Many of these wetlands are under threat from conversion to intensive agriculture, excessive disturbance and failure to recognize their importance. Key actions for the conservation of palustrine wetlands should include prioritizing conservation of these ecosystems through policy development, updating the historical database to reflect current conditions through renewed mapping efforts, and developing an action plan that seeks to conserve remaining wetland systems for the benefit of the species that require them, including people.

Acknowledgments

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Notes

1. The wetlands layer is achieved and available at https://www.arcgis.com/home/item.html?id=f6412d57457645fa9353dcdd9ea544fa (accessed September 15, 2018).
2. The common names applied to most plant species are not standardized so common names applied to the same species of plant often vary greatly among geographic regions. For example, the English plant name "reed" is applied to plants in the genus *Scirpus* in the western United States, *Phalaris* in the eastern United States, and *Eleocharis* in Southeast Asia.

[3] International Union for the Conservation of Nature, IUCN Redlist, http://www.iucnredlist.org (accessed July 5, 2018).

[4] Ibid.

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4

The impact of the East-West Economic Corridor on the livelihoods of forest-dependent communities in Vietnam

Bui Duc Tinh and Pham Xuan Hung

The East-West Economic Corridor (EWEC) is part of a major infrastructure project designed to promote economic integration in the Greater Mekong Subregion (GMS), and has been supported by the Asian Development Bank (ADB). The EWEC begins in the west at the port city of Mawlamyine in Myamar, crosses the Thai provinces of Sukhothai, Phitsanulok, Phetchabun, Khon Kaen and Mukdahan, continues across the Mekong River into the province of Savannakhet in Lao PDR, and ends in Vietnam, crossing the Quang Tri and Thua Thien-Hue provinces and terminating in Danang. The EWEC's stated aims are to promote socioeconomic development, infrastructure improvement, tourism, agriculture and poverty reduction (ADB 2009). The trans-Mekong region road network also aims to create more market opportunities and distribute a greater share of income, in particular to households in marginal or remote areas in each participant country. By increasing cross-border trade, regional integration is also expected to lead to increased production, higher consumption, and more waged employment (Isono 2010). Its proponents also argue that the EWEC will help allocate resources more efficiently and transfer technology.

However, since its completion, scholars have observed that the extent and intensity of these benefits vary widely among countries, regions, and individuals (Winters 2000; McCulloch et al. 2001). More competition and the rising role of market forces may be worsening employment and livelihood opportunities for socially and economically disadvantaged groups and lead to even more inequitable income distribution. There have been worrying patterns and trends of job losses to migrants or better-skilled outsiders, particularly in disadvantaged communities; rapid natural resource depletion; as well as inequality among the various stakeholders (Gachassin et al. 2010; Nga 2008).

The EWEC was initiated in 1998 at the 8th Ministerial Conference of the GMS in Manila, to promote the development and economic integration of Myanmar, Thailand, Cambodia, Laos and Vietnam. The EWEC, which became operational in 2006, is the first transport corridor to run right across mainland Southeast Asia, with a distance of 1,450 km. It aims to support rural and border area development in order to provide employment and increase earnings of low-income groups. It also seeks to enhance mobility, to promote cross-border trading and enable rural communities to gain better access to market and employment opportunities. The EWEC runs through large areas of mainly forest-dependent communities, including approximately 34 percent of Kyaikmaraw, Myanmar; 45 percent of Savannakhet province, Laos; and 37 percent of Quang Tri province, Vietnam. All three areas have a significant number of people living below the poverty line. Livelihoods in these regions rely on subsistence agriculture—food cultivation, raising cattle, and collecting non-timber forest products (NTFPs) for sale. Very few households are involved in planting cash crops for the market. While many studies have investigated the ongoing impact of the new GMS economic corridors (highways) on poverty, cross-border trade, investment, infrastructure development and the environment (Nga 2008; Sirivanh 2007; Srivastava 2012; Zhu 2006; Keoamphone 2007), there has been a lack of information about their consequences for forest-based livelihoods and forest resources (Phuc and Kalkins 2012).

Several recent studies (Isono 2010; Montague 2010; Phuc and Kalkins 2012) have indicated a strong relationship between the transport corridors in general, and the EWEC in particular, and economic development; job generation; income generation and poverty reduction. Other researchers (Keoamphone 2007; Nga 2008) have investigated the social and environmental impact of these economic corridors in the Mekong Region on local communities. The EWEC is regarded as a foundation for the beginning of many general agreements on trade and services, and as a catalyst for the development of important commercial zones. Nevertheless, there is a gap in the literature on the EWEC's impacts on the livelihoods of forest-dependent villagers. The key questions addressed by this chapter are: How have the livelihoods of forest-dependent communities changed since the increased regional integration brought about by the EWEC? Why have some communities benefited while others declined? This chapter investigates the impacts of the EWEC through a case study of forest-dependent villagers in Vietnam, and compares livelihood changes between similar households living within the EWEC area and those living in more remote areas without access to the EWEC.

Using the Sustainable Livelihoods Approach (SLA)

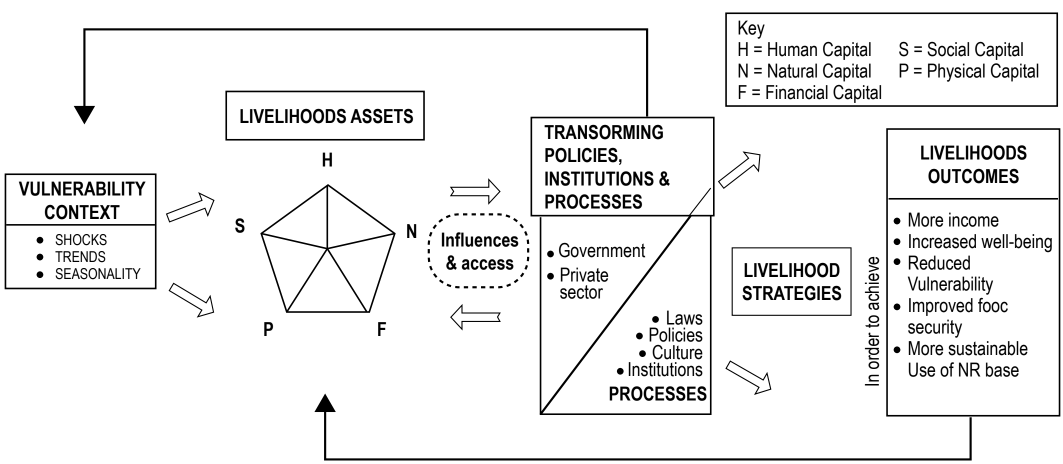
The Sustainable Livelihoods Approach (SLA) developed by the Department for International Development (DFID 1999) was used in this study to investigate the five core assets, human, social, physical, financial and natural capital, upon which livelihoods are built among forest-dependent communities in selected villages. The study compares changes to livelihoods and forest resources *before* and *after* the establishment of the corridor, in communities that are within and outside the EWEC.

Livelihood may be defined as the adequate stocks and flows of food and cash required to meet basic needs (Chambers 1986). Security refers to the secure ownership of, or access to, resources and income-earning activities, including reserves and assets to offset risk, ease shocks and meet contingencies (Frankenberger 1996). Based on these definitions, Chambers and Conway (1991) proposed a definition of livelihood that is most commonly applied at the household level: "A livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living." Scoones (1998) classified livelihood capital into five main assets, namely human, natural, physical, financial, and social capital. The five forms of capital do not share the same characteristics. Human capital is perhaps the most important factor; it refers to the educational level and health status of each household member. Natural capital refers to biophysical elements such as water, soil, trees, minerals, etc. These are natural resources that can be renewed easily. Physical capital comprises assets brought by economic production processes such as housing, roads, tools, machines or irrigation canals. Financial capital refers to liquid assets, such as money, bank accounts, and stocks or bonds, which can be used to purchase various goods and services or to acquire other types of assets. Social capital refers to the networks and associations in which people participate, and from which people can receive assistance in order to enhance their means of living (Scoones 1998).

Chambers and Conway (1991) also discussed the concept of “sustainability” as an important aspect of livelihood. A livelihood is sustainable when it can cope with, and recover from, stresses and shocks and maintain or enhance its capabilities and assets both in the present and the future (DFID 2000). Livelihoods are not simply a localized phenomenon. On the contrary, they are connected through environmental, economic, political and cultural processes at broader regional, national and even global levels (Mtango and Kijazi 2014). Livelihood sustainability may be classified into environmental and social sustainability. Environmental sustainability concerns the external impacts of livelihoods on local and global resources and other assets. Meanwhile, social sustainability relates to the internal capacity of households to withstand outside pressures, to cope with stresses and shocks, and to retain their ability to improve and enhance their living standards.

To apply the livelihood concept in more detail, the Department for International Development (DFID 1999) developed a framework for analyzing the sustainability of livelihoods, which is considered as a useful tool to improve the understanding of livelihoods. The SLA framework (fig. 4.1) presents the main factors affecting the livelihoods of the poor, as well as the interrelationships between these factors.

Figure 4.1. Sustainable livelihood framework (DFID 1999)



Vulnerability refers to the external factors that affect household assets and may be comprised of critical trends, shocks and stresses. Table 4.1 proposes some examples of vulnerability context:

Table 4.1. Vulnerability context and sustainable livelihoods

Trends	Shocks	Seasonality
Population trends	Human health (diseases)	Of prices
Resource trends	Natural shocks (disasters)	Of production
National/International economic trends	Economic shocks (price)	Of employment opportunity
Trends in governance	Conflict (livelihood assets)	
Technological trends	Crop/livestock health	

The factors shown in table 4.1 are important because of their direct impact on asset status and livelihood options. Assets such as houses and furniture can be destroyed by natural hazards such as storms or floods. Meanwhile, the overexploitation of forest resources and changes in forest resource management may affect the availability of these resources for communities. Furthermore, the income of farmers can be easily affected by factors such as sudden fluctuations in commodity prices, rainfall shortages, or a lack of seasonal non-farm job opportunities to supplement agricultural income. However, not all trends mentioned in Table 4.1 are negative or cause vulnerability. Some can bring benefits. For instance, administrative changes can result in vulnerable communities getting more government support in areas such as education, health services, technical training, or access to low interest rate loans.

Using the sustainable livelihood framework (Carney 1998), previous studies (Davis 2000; D'Haese et al. 2007; Cotton 2011) have investigated the impacts of regional economic integration projects similar to the EWEC. The studies show that the SLA framework has several advantages over the conventional neoclassical microeconomic approach when analyzing the impacts of a road construction project at the household level. SLA recognizes that households, particularly disadvantaged groups, derive their living conditions from a multitude of activities based on the five core assets. Material assets alone do not determine the livelihood strategy of households. It also recognizes that institutional frameworks, such as, policy, laws, customs and gender relations, affect livelihoods.

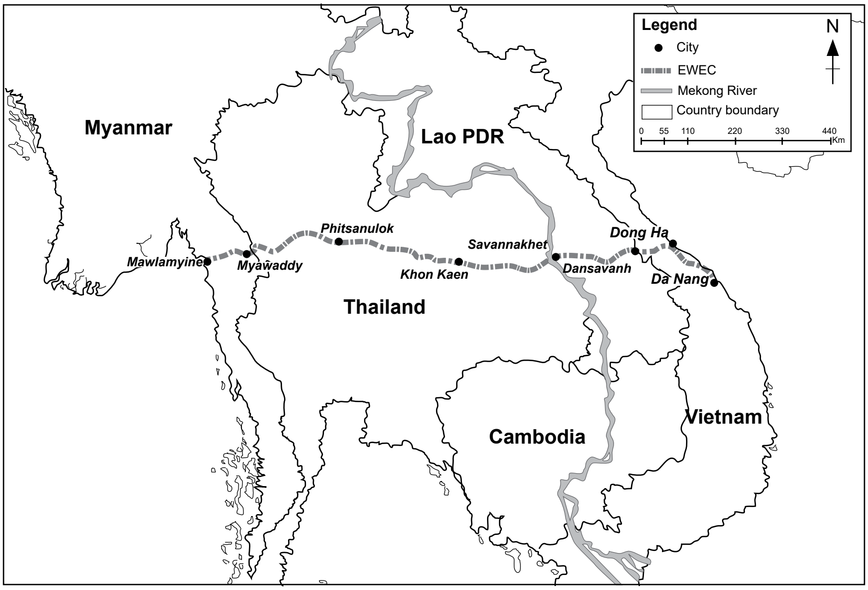
Using the SLA for road construction impact analysis, Mu and van de Walle (2011) argue that roads have enhanced the development of local markets and non-farming employment, particularly for rural communities. However, disadvantaged communities and households with low education have not benefited, as many lost social relationships and participation in community activities. For example, only a small number of local households were able to establish shops along the new road (Mu and van de Walle 2011). Zhu (2006) found that local villagers were also affected by labor migration: monoculture crop plantations, such as oil palm and rubber, are often owned by businessmen who migrated from the lowlands and who recruit workers from elsewhere. Villagers in the area who lost their livelihoods became involved in illegal trading or had to migrate to seek work, ending up in gold mines and the sex trade. Local communities, particularly disadvantaged groups, are at very high risk and vulnerable to the socioeconomic changes brought about by these 'economic corridors' (Nga 2008).

Zhu (2006) also highlighted the negative impacts of the North–South Economic Corridor on forest resources and biodiversity due to increased accessibility to the forests in and across the border from Xishuangbanna. Illegal logging and wildlife trafficking have increased along with a decrease in forest resources, particularly in the areas closer to the road, while cash crop plantations, such as oil palm and rubber, have expanded along the buffer zone areas near the roads (ibid.).

EWEC in Quang Tri province, Vietnam

Located in Vietnam's central region, Quang Tri province shares a border with Quang Binh province to the north, Thua Thien-Hue to the south, Savannakhet province (Laos) to the west. Quang Tri province is characterized by a steep mountain range in the west and narrow deltas in the east; it is considered an important transportation hub due to its location as the starting (or ending) point of the EWEC (see fig. 4.2).

Figure 4.2. East-West Economic Corridor and study site showing key cities



Quang Tri province has a total area of 4,760 km^2, comprising 301,994 ha of with farming land, 41,421 ha of non-farm land, and 131,284 ha of spare land. In addition, it has abundant forest resources: in 2009, the province was covered by 220,797 ha of forests. The quality of natural forest has decreased, although tree cover has slightly increased due to the rapid development of commercial acacia, rubber and pine plantations (Quang Tri Statistical Yearbook 2015). In 2015, the population of Quang Tri province was 601,672, consisting of 136,743 households with an average family size of 4.4 persons; 170,073 people lived in urban areas (about 28 percent of the total), with the majority living in rural areas. About 346,287 were employed as laborers (about 57 percent of the total), the majority of whom worked in the agricultural sector, including aquaculture (ibid.).

The first case study was conducted in Dakrong district, a mountainous area about 65 km to the west of Dong Ha city. Dakrong is spread over 1,151 km^2 and has a population of 76,000 people. In 2015, nearly 76 percent of the district was covered by forests and about 90 percent of the population is dependent on forest resources for their livelihood (GSO 2015). Dakrong district consists of one town and thirteen communes, two of which (17 villages) were selected for the study: Banang commune with

528 households and Avao commune with 566 households are grouped as forest-dependent villages outside the EWEC; they are 50 km to 120 km away from the main road respectively.

The second case study was conducted in nearby Huong Hoa, a mountainous district in Quang Tri province sharing a border with Laos in the west and southwest, and Quang Binh province in the north and Dakrong in the east. It has a total population of 80,027 persons living in about 4,247 households; about 83 percent of these live in forest-dependent villages. The total area of Huong Hoa district is 115,283 ha, about 64 percent of which is forested. There are twenty-two communes and two towns located near the border with Laos (Huong Hoa Statistical Office 2015). The EWEC-FC project randomly selected two communes within the EWEC zone for survey, including the Thuan commune with 613 households and the Huong Tan commune with 710 households. These communes were selected as representative of communities living within the economic corridor.

Methods

A mixed research methods approach was used to collect quantitative and qualitative data as well as additional secondary information. Secondary data was collected from different sources, including from government departments, customs offices, and statistical yearbooks. Data regarding the EWEC and its contribution to socioeconomic development was obtained from the Quang Tri Customs Office. In addition, a literature review was also undertaken using relevant books, journals, and archival materials.

Focus group discussions (FGDs) and key informant interviews (KIIs) were conducted to collect qualitative information, such as local responses, narratives and stories regarding the impact of the EWEC on local livelihoods. A total of sixteen KIIs and fourteen FGDs—eighteen groups of forest-dependent villagers living within the EWEC and six groups living outside the corridor—were conducted at the case study sites. Each FGD included seven to ten participants.

Of the 529 households in the study site, 249 households were selected for the research survey in Quang Tri. A semi-structured interview was designed to collect primary information on each household, including demographic information, changes in the five assets for sustainable livelihoods, and the impact of the EWEC on livelihoods. The completed household surveys were cross-checked and entered into the Statistical Package for the Social Sciences (SPSS) for analysis.

Impacts on local livelihoods

In this section we will use the information gathered to analyze claims that the EWEC would improve socioeconomic development through increasing opportunities for trading, generating jobs and income, and contributing to poverty reduction.

Human capital

Human capital is defined as the knowledge, skills, experience, and health, which affect an individual's capacity to learn, train and work. It is utilized when individuals engage in production and is reflected in the productivity and efficiency of their labor (Binh 2009). In the case of rural livelihoods, these factors together enable people to pursue various livelihood strategies and achieve their livelihood objectives.

The effect of the EWEC on human capital can be estimated based on households' perceptions about their ability to access educational facilities and healthcare services. The survey results show that forest-dependent villagers have experienced a significant improvement in both educational facilities and healthcare services since the highway was built. Around 83.6 percent of respondents living in communities within the EWEC rated an improvement in the education of their children, with only 10.2 percent of surveyed households stating that there had been no change. This is consistent with the findings of FGDs and KIIs where the participants reported that, thanks to the EWEC, their children had better access to education, particularly high school and tertiary training. The EWEC has improved transportation and mobility, and hence access to better education and healthcare. Many participants also claim that their children have a better chance to pursue high school and university studies in cities. This is one important and sustainable change in their livelihoods. Similarly, access to healthcare services was also highly rated by respondents, with 79.1 percent of households living in forest-dependent villages within the EWEC agreeing that these services have improved significantly since the highways were built; this compares with about 61 percent for similar villages outside the EWEC. Nearly 95 percent of respondents stated that their families often visit doctors at commune, district or even provincial healthcare centers when they are sick.

Natural capital

Land is considered as the most important capital required for economic development, particularly for forest-dependent villagers. Land is the most valuable asset for local livelihoods, especially for poor and marginalized groups. In this regard, the building of the EWEC has significantly changed land-use patterns of many forest-dependent villages in Quang Tri province.

The livelihoods of forest-dependent communities are relatively diverse and require access to forest land for farming and resources. Farm plots are approximately 5 m^2 per household, slightly more than half of the total household land-use area. However, there have been significant changes in agriculture since the completion of the EWEC, with a dramatic shift from subsistence to cash crops in villagers within the transportation corridor. Villagers have converted their rice fields and forest farmland to grow cash crops such as bananas, coffee, and cassava, particularly for export.

The EWEC has clearly improved access to markets, thus farmers are able to buy cheaper inputs (seed, fertilizer, pesticides) and to sell their produce at better prices. Forest-dependent villagers realize that they can earn more from growing commercial crops, and seek to expand their farms. The FGDs and KIIs in 2016 revealed that villagers living alongside the EWEC were encroaching on forest land, converting their plots for cash cropping. For instance, banana plots doubled from 1.134 m^2 in 2005 to 2.216 m^2 per household in 2016. The discussions and interviews confirmed that about 80 percent of the natural forest in villages within the EWEC has declined due to increased logging and cash crop production.

Although the expansion of cash crops has made a significant contribution to income improvement, the rapid development of cash cropping could be unsustainable for two reasons. First, forest-dependent communities have very little power in the long value chains of agricultural products. They lack market information and must accept the offered price in the face of price fluctuations. Collectors and exporters often collaborate to set the prices. Second, forest-dependent villagers tend to adopt mono-cropping rather than multiple cropping, given declining forest access and alternative livelihood options. Traditional livelihood sources

Table 4.2. Household land use comparison, 2005 and 2015 (m^2)

Land type	Households within EWEC				Household outside EWEC			
	2005		2015		2005		2015	
	Mean	%	Mean	%	Mean	%	Mean	%
1. Residential land	241.05	1.797	240.32	1.3	539.41	5.2	823.48	5.9
2. Annual cultivation	8,564.10	63.8	10,496.11	56.6	5,311.98	51.5	7,916.80	56.7
Wet-rice	1,080.68	8.05	1,190.45	6.4	838.84	8.1	875.00	6.2
Upland-rice	3,222.41	24.08	3,346.14	18.0	681.82	6.6	529.85	3.7
Bananas	1,051.70	7.8	625.00	3.37	1,134.71	11.02	2,216.42	15.8
Cassava	2,579.89	19.2	4,695.45	25.3	2,192.56	21.2	3,608.96	25.8
Vegetables	55.78	0.41	50.30	0.2	141.74	1.3	161.45	1.1
Ginger	1.14	0.01	1.40	0.08	12.81	0.1	94.40	0.6
Others	444.43	3.3	587.36	3.1	309.50	3.0	412.03	2.9
3. Perennial cultivation	1,573.30	11.7	2,966.88	16.0	3,685.12	35.7	4,146.27	29.7
Coffee	1,327.27	9.8	720.82	3.8	3,641.32	35.3	3,692.16	26.4
Rubber	0.00	0.0	0.00	0.0	0.00	0.0	347.01	2.4
Pepper	7.39	0.05	29.55	0.1	40.50	0.3	28.36	0.2
Others	238.64	1.7	2,209.63	11.9	3.31	0.0	78.73	0.5
4. Forest	948.86	7.075	1,834.09	9.8	454.55	4.4	0.00	0.0
5. Non-used land	2,079.55	15.5	1,913.64	10.3	264.46	2.5	784.70	5.6
6. Others	3.98	0.03	1,046.55	5.6	23.97	0.2	231.75	1.6
Total	13,410.83	100.0	1,8528.49	99.1	10,296.02	100	13,949.42	100

such as NTFPs or handicrafts have disappeared, leaving them with no supplementary sources of income. When harvests are good but prices are bad, they can face difficulties.

Physical capital

The improved road network has created better access to markets and social services such as healthcare and education, as well as electricity and clean water. Of the surveyed forest-dependent villagers living within the EWEC, 87.3 percent confirmed its significant contribution to their access to services and utilities in comparison with about 53.6 percent of surveyed households living in villagers outside the EWEC.

In the focus groups, local residents pointed out that more connecting roads have been built since the EWEC's launch, improving their access to markets, health and education facilities, and electricity and clean water. About 70 percent of respondents living within the EWEC confirmed that transporting their produce for sale has become cheaper as opposed to only 47 percent of those living far from the EWEC.

Table 4.3. Types of housing (%)

Areas	Permanent houses	Semi-permanent houses	Weak or temporary houses	Total
Households outside EWEC	0.9	13.6	84.5	100
Households within EWEC	28.6	23.3	48.1	100

Our study finds differences in housing between forest-dependent villagers within the corridor compared to those away from it. More than 50 percent of the villagers along the EWEC now live in permanent and semi-permanent houses, while about 48 percent live in temporary houses. This contrasts with areas away from the EWEC, where only 14.5 percent live in permanent or semi-permanent houses, while up to 84.5 percent live in temporary houses. The differences in housing among forest-dependent villagers are due to income variations tied to their location vis-à-vis the EWEC, as the next section elaborates.

Financial capital

Income is an important indicator of household living standards. Table 4.4 indicates significant differences in income between households living within and outside the EWEC, before and after its establishment. Our study reveals that the income of households living within the EWEC has significantly increased from an annual average of VND26.95 to 97.42 million per household over the first ten years, equivalent to US$1,200 in 2005 to US$4,000 per household in 2015. In addition, their income is generated from various sources such as crop farming, animal husbandry, NTFP collection, labor migration and services. Among these, cultivation, including that of annual and perennial crops, is the main activity, accounting for about 57 percent of the total annual income. Animal husbandry is also an important income source of surveyed households in the research area. The second most important source of income is from non-farming activities, such as self-employed services, timber processing, and agricultural produce collecting, generating a minimum income of VND3.41 million to VND25.78 million, about 26.46 percent of total household income. The results reveal much lower incomes for forest-dependent villagers living away from the EWEC, about VND21.95 million, US$1,000 in 2005 before the corridor was built, and reached about VND66.9 million (US$3,200) per household. It is evident that forest-dependent villagers living within the EWEC have much higher incomes than those living in villages situated further away.

This study also investigated the impact of the EWEC on changes in the living standards of both groups by compiling information on monthly household expenditure. Table 4.5 illustrates that communities living within the EWEC have better living conditions than those of households living outside it. The average expenditure of households within the EWEC zone in the four weeks before the survey was VND 2,444.2 (US$120) per household in comparison with VND 1,732.14 (US$80) per household living outside it. The findings also indicate that households living within the EWEC area spent on more costly foods such as fish, meat, eggs, and milk as well as on education and healthcare. Furthermore, other measures of consumption for information and communication services, such as mobile phones, desk phones and internet subscription, revealed a considerable difference between the two groups of households (table 4.4).

Table 4.4. Household income sources, 2005 and 2015 (VND m/year/household)

Activities	Households living outside EWEC				Households living within EWEC				Comparison between both in 2015	
	2005		2015		2005		2015			
	Value	%	Value	%	Value	%	Value	%	Value	Sig.
Cultivation	12.06	54.96	41.05	61.35	14.13	52.42	57.55	59.08	16.5	0.015 [a]
Animal raising	3.78	17.24	9.52	14.23	4.49	16.64	5.17	5.31	-4.35	0.336
Timber	0.21	0.96	0.24	0.35	0.22	0.83	0.11	0.11	-0.13	0.383
Non-timber	2.32	10.59	3.55	5.31	1.29	4.78	0.83	0.85	-2.72	0.002 [a]
Services	1.99	9.09	6.08	9.09	3.41	12.66	25.78	26.46	19.7	0.003 [a]
Others	1.57	7.16	6.47	9.67	3.42	12.67	7.99	8.20	1.52	0.588
Total	**21.95**	100	**66.91**	100	**26.95**	100	**97.42**	100	**30.51**	**0.004** [a]

Note: [a] significant difference at alpha = 5%.
Source: Household survey, 2016.

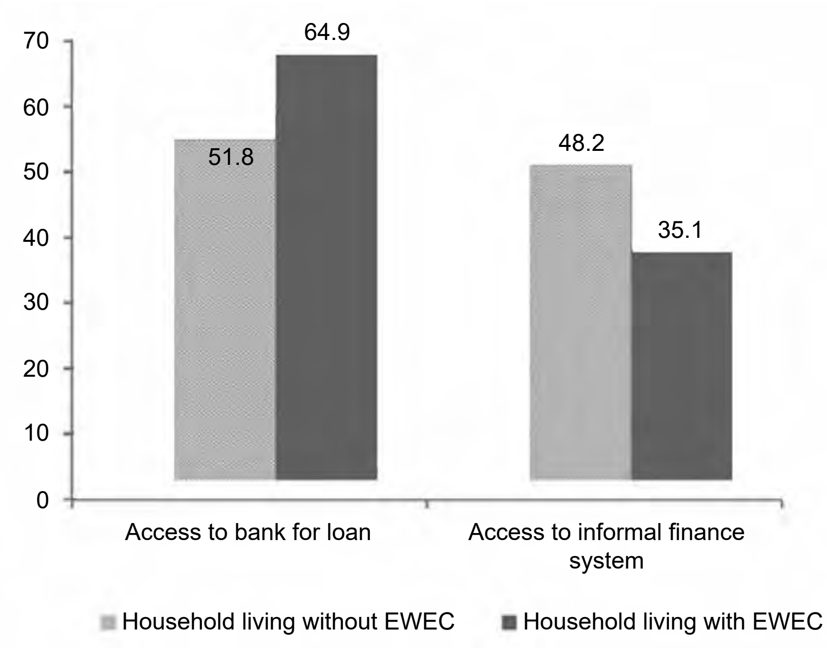
In the study area, the lack of financial capital has been one of the most common difficulties that constrain households from adopting new livelihoods or improving their living conditions. About 65 percent of total surveyed households living within the EWEC had access to different sources of loans compared with about 48 percent of total surveyed households living outside the EWEC. About 64 percent of households living within the EWEC had access to formal banking services in comparison with about 51 percent of the surveyed households living outside the EWEC. However, about 36 percent of forest-dependent villagers living within the EWEC had access to informal banking and credit sources as opposed to about 49 percent of their counterparts living further away. It is important to note that the EWEC has improved household access to the formal banking system. The average household loan within the EWEC area is about VND27 million in comparison to about VND16 million among households living outside the EWEC.

Table 4.5. Monthly household expenditure in 2015 (VND '000/mth)

Expenditure items	Households living outside EWEC		Household living within EWEC		Mean difference	Sig.
	Value	%	Value	%		
Rice	703.68	40.62	624.59	25.55	-79.09	0.102
Vegetables	74.91	4.32	103.51	4.23	28.60	0.024 [a]
Fish and Meat	267.55	15.45	487.12	19.93	219.57	0.00 [a]
Eggs and Milk	74.41	4.30	169.03	6.92	94.62	0.002 [a]
Spices	8.58	0.50	36.01	1.47	27.43	0.00 [a]
Water and Alcohol	102.37	5.91	198.41	8.12	96.04	0.001 [a]
Communications	51.68	2.98	95.40	3.90	43.72	0.004 [a]
Electricity	37.19	2.15	88.13	3.61	50.94	0.00 [a]
Health care	118.55	6.84	195.22	7.99	76.68	0.436
Education fee	29.91	1.73	121.87	4.99	91.96	0.042 [a]
Fuel	196.20	11.33	139.14	5.69	-57.06	0.524
Others	83.45	4.82	185.75	7.60	102.29	0.042 [a]
Total	**1,732.14**	100.00	**2,444.17**	100.00	**712.03**	0.003 [a]

Note: [a] significant difference at alpha = 5%.
Source: Households survey, 2016; [a] mean difference at alpha = 5%

Figure 4.3. Household access to credit from banks and informal systems



Source: Household survey, 2016.

Social capital

Social capital comprises trust, norms, and networks of association representing any group which gathers together for a common purpose (Garson 1998). In this study, social capital is examined through three aspects: including access to jobs, community cohesion, and violence.

This study found that forest-dependent villagers living within the EWEC confirmed that they now have better job opportunities and improvement in incomes. About 46 percent of respondents living within the EWEC stated that this corridor has provided them with more job opportunities. These opportunities, however, were mainly in the agricultural sector, such as growing cash crops and collecting and processing agricultural products, rather than labor migration. Focus group participants reported that they found it hard to migrate out of their village to seek work, as they lacked the necessary educational qualifications and skills. Meanwhile, about 27 percent of the labor force living in communities along the EWEC are migrants from delta districts and other provinces. Villagers living away from the EWEC have seen fewer livelihood options and employment opportunities. The study found that not many local people migrated to seek jobs in the special economic zone and urban industrial zones.

This study also investigated the impact of the EWEC on community cohesion and violence. Focus group discussions revealed that there have been differences in community cohesion and social violence between the two groups of villages since the advent of the EWEC. Villagers living within the EWEC have tended to replace traditional customs in wedding and funeral ceremonies. Reciprocal labor exchange, a practice in the past when households needed extra labor for special events such as house building, harvests, weddings and funerals, has stopped and been replaced by daily paid-employment. The local population in these forest areas have also been increasingly involved in government-run festivals, elections and performances. Many youth in villages within the EWEC tend to spend more time at leisure rather than at work; their pastimes include illegal motorcycle racing, watching television, drinking alcohol and gambling. Meanwhile, forest-dependent villagers living away from the EWEC still continue to maintain community cohesion through special events such as mutually-assisted house construction, weddings, harvesting and traditional customs.

Drug use and petty violence have also increased since the coming of the EWEC. About 38 percent of the total respondents in the corridor confirmed that there has been a rapid increase in violence, often linked to drug trafficking, prostitution and theft. In particular, the theft of cash crops such as bananas, coffee beans and latex rubber has increased since the EWEC was completed (of course, this is not the case in the villagers outside the corridor which are still not growing these crops to the same extent).

EWEC and cross-border trade

The EWEC has increased economic integration through cross-border trading in the Mekong Region. As much as US$1,351 million worth of goods were transported through the EWEC in 2008, which is 7.5 times higher than the value of goods traded in 2002. Cross-border trading between Myanmar and Thailand amounted to US$419.9 million in 2008; between Thailand and Laos, US$413.2 million, about 22 times higher than the 2002 value; between Vietnam and Laos US$155.6 million, compared to about US$80 million in 2000 (ADB 2010, 2013).

To strengthen the linkages with regional and international production networks, as well as to boost cross-border trading in the EWEC, ADB and Japan provided technical support to establish Special Economic Zones (SEZs) along the corridor. The establishment of SEZs is intended to facilitate private investment. In the shared prosperity narrative of the EWEC's proponents, SEZs are seen as a "complementary initiative" to economic corridors which will generate more non-farming jobs for local communities. Vietnam, Thailand, and Laos, have therefore emphasized leveraging regional connectivity to develop their border provinces along the corridor in order to expand their economic base. This policy position is consistent with earlier national plans to develop border towns as "trade points" or "economic gateways" (Lainé 2013).

Accordingly, a number of SEZs have been constructed along the EWEC, such as the Savan-Xeno Special Economic Zone in Savannakhet, Laos; Lao Bao Economic Zone in Quang Tri, Vietnam; and Mae Sot and Myawaddy Special Economic Zones in Thailand and Myanmar. These zones are expected to attract more private investment and generate more jobs for local communities (Krainara 2015). However, local people have found it difficult to obtain employment in these zones, as mentioned above. Meanwhile, the SEZs have often led to land grabs, rapid deforestation, and the migration of outsiders into these areas. A Thai government spokesman, commenting on the Mae Sot SEZ, stated that "The government might need to revoke the protected forest status of some areas to allow development to go ahead" (*Bangkok Post* 2013). Environmental groups have fiercely criticized this side-stepping of normal procedures by the government, stating it denies the people their right to manage natural resources. Myanmar migrant workers living in Thailand also expressed concerns about their livelihood security (Khin 2015). Meanwhile, many SEZs have been unsuccessful in attracting investment from local and foreign firms. In the Lao Bao SEZ in Quang Tri province, Vietnam, many investors withdrew their capital.

The SEZs were intended to boost commerce along the EWEC, and help to generate income and employment for local low-income and vulnerable groups. However, forest-dependent communities, especially those in the remote mountain ranges, remain poor and marginalized. Their income is strongly dependent on subsistence agriculture, livestock raising, forest cultivation and NTFP collection. Only a few households are involved in non-farming services and cash crop cultivation.

Conclusion

The EWEC has attracted more investments in infrastructure expansion, including connecting roads. Many communities within the corridor have seen considerable socioeconomic improvement. This is consistent with the conclusion of other studies investigating the impact of economic corridors on local livelihoods (Guina 2008; Isono 2010; Montague 2010). Cross-border trade and agreements and non-farming activities have also expanded (Phuc and Kalkins 2012). However, forest-dependent households have had less opportunity to expand their livelihoods with non-farming activities as they lack the resources including capital, education and skills required to access these new forms of employment. Moreover, the development of road infrastructure, SEZs and private enterprise have led to rapid land acquisition by outsiders and deforestation, in turn, affecting the livelihoods of forest-dependent communities.

The policy narrative of the EWEC highlights the increased trade flows that will promote economic activities and development and reduce poverty along the corridor. While the EWEC has enabled better and cheaper transportation of goods among the Mekong countries and expanded cash crop production, there have been no clear benefits to local forest-dependent communities whose lives and livelihoods are largely embedded in subsistence agriculture and forest-use. In terms of job creation, the corridor has not produced substantial employment opportunities for these communites and tends to reduce the demand for work among migrant agricultural laborers. Indeed, the EWEC has attracted migrants from lowland districts with higher levels of literacy, access to capital and/or skills to benefit from the new jobs available since the launch of the corridor. Local forest-dependent communities, however, with their lack of the relevant knowledge and skills required to work in enterprises or factories, and lower levels of literacy, have been unable to compete with outsiders to take advantage of the new job opportunities.

The road networks, moreover, have put more pressure on land use and forest resources. Notably, there has been a significant change in land use patterns, including forest land conversion by forest-dependent households seeking to expand their cash crop areas.

While the EWEC has provided more access to financial capital and formal institutions, it has resulted in the deterioration of social capital: communities along the corridor have experienced an increase in violence and the erosion of cultural traditions especially among the younger generation.

For many forest-dependent communities, the EWEC has resulted in better access to credit and services, such as education and healthcare. But not all communities are able to take advantage of these services given that many live in remote mountainous areas. In sum, the benefits of the EWEC seem more evident for communities living within the corridor areas rather than those who live further away; the EWEC seems to be benefiting those who already possess the know-how and skills to take advantage of the new opportunities and are able to compete. Communities living further away EWEC are often reduced to losing their lands and forest-based livelihoods, and unable to access the services and benefits, the promise of shared prosperity continues to remain elusive.

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5

Development of national REDD+ strategy in Cambodia, Myanmar and Thailand

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Mitigating the impacts of climate change in the forestry sector has been a focus of both the United Nations Framework Convention on Climate Change (UNFCCC) negotiations process and in academic literature over the past decade. In 2005, citing results from the Intergovernmental Panel on Climate Change (IPCC) study in 2000 on the rates of deforestation in developing countries and corresponding carbon emissions, the governments of Papua New Guinea and Costa Rica, supported by the governments of Bolivia, Central African Republic, Chile, Congo, Democratic Republic of the Congo, Dominican Republic and Nicaragua, requested that the UNFCCC include in its policy dialogue an agenda item to discuss and develop scientific, technical, policy and capacity responses to address emissions from tropical deforestation (IPCC 2000, UNFCCC 2005). This proposal was accepted by the UNFCCC, and has evolved into what is now known as REDD+, which stands for Reducing Emissions from Deforestation and Forest Degradation, and (+) the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries (UNFCCC 2010).[1]

As a concept, REDD+ has been a success at the international level in terms of garnering support for the development of a comprehensive framework through international negotiations under the UNFCCC. This has served to focus global attention on forest governance and sustainable development issues tied to climate change in developing countries. However, various studies have raised potential social (Angelsen et al. 2012) and environmental concerns (Nguon and Kulakowski 2013) that may arise when REDD+ is implemented on the ground. To address these potential concerns, the Conference of the Parties (COP) to the UNFCCC have negotiated and published decisions on REDD+ that include measures to reduce social and environmental harms exerted through the implementation of REDD+ activities. Adopted at COP19 of the UNFCCC, the Warsaw Framework for REDD+ mandates that to be eligible for the UNFCCC REDD+ mechanism and performance-based payments, participating countries need to have in place four required building blocks/ elements (UNFCCC 2013). These include: a national REDD+ strategy or action plan (NRS); a national forest reference emission level and/or forest reference level (FREL/FRL); a robust and transparent national forest monitoring system (NFMS) for REDD+ activities; and a Safeguard Information System (SIS).

This decision means that REDD+ participating countries shall set out and define their national policies and measures in their national REDD+ strategies or action plans to be eligible to receive results-based finance for their REDD+ efforts. To design and develop this strategy or action plan, countries will have to generate information on key topics such as social and environmental safeguards, grievance mechanisms, benefit sharing, identification of drivers of deforestation and degradation, measuring, reporting and verification (MRV), NFMS, forest reference emission levels and forest reference levels (FRELs/FRLs), and (if applicable) national REDD funds and/or registries (UNFCCC 2013, 2015). Many REDD+ countries, including Cambodia, Myanmar and Thailand, have begun work to develop their national REDD+ strategies.

Although there are globally more than 60 countries aiming to implement REDD+ activities under the UNFCCC (CIFOR 2012), there is no official guidance from entities such as the UN-REDD Programme, the World Bank's Forest Carbon Partnership Facility (FPCP), or even the UNFCCC on how to develop national REDD+ strategies. While it is acknowledged that a few of the REDD+ participating countries have completed their draft national REDD+ strategies (for example, Tanzania, Indonesia, Vietnam), there is very limited documented knowledge on the design process that these countries followed both in the academic and policy arena. In addition, the level of detail in these existing national REDD+ strategies vary significantly. Therefore, countries that are in the process of developing their national REDD+ strategies such as Cambodia, Myanmar and Thailand are obliged to determine their own approach to complete this important task that would help transition them from the initial readiness phase to the second phase of REDD+ implementation. While there have been academic peer-reviewed articles on different aspects of REDD+ in the three countries based on experiences with pilot projects (Suiseeya and Caplow 2013, Salvini et al. 2014, Fischer et al. 2016), these studies have not addressed how state and non-state actors are endeavoring to produce national level REDD+ policy that will be compliant with requirements from the UNFCCC (Nguon 2018).

In this context, the main objective of this chapter was to document and compare the processes, barriers and opportunities that Cambodia, Myanmar and Thailand have and/or will face in their national processes to design their REDD+ national strategies. Overall, the main rationale for this chapter is to provide insights and guidance to policy-makers by identifying challenges and solutions on how key components for a national REDD+ strategy could be developed, with particular reference to improving the social and environmental well-being of forest-dependent communities in REDD+ participating countries. The diverse social, economic, ecological and political settings as well as the different rates of REDD+ implementation in these three countries will increase the applicability of lessons learned from this chapter to other REDD+ participating countries. In short, the chapter provides guidance on how national REDD+ strategies could be developed based on empirical field experiences in Southeast Asia.

Research design

Theoretically, this chapter empirically explored claims from political ecology (Robbins 2011) and knowledge systems in sustainability science (Bebbington and Bury 2009) literature regarding interactions between state and non-state actors in producing national policy knowledge that would be salient, credible, and legitimate for relevant stakeholders. Methodologically, this chapter utilized qualitative comparative analysis (Sehring et al. 2013) which includes methods such as key informant interviews, observations of REDD+ policy processes, and extended archival research to answer key questions. The interviews offered a first-hand account of the criteria that different groups of stakeholders use and their justifications for using those criteria to assess key variables to questions. Observations of REDD+ policy processes in the three countries (e.g. meetings, consultations) provided information on the participation and engagement of different groups of stakeholders in the production, examination and dissemination of knowledge on REDD+ safeguards, grievance mechanisms, and stakeholder empowerment. Finally, archival reviews were conducted to first, validate, compare, and contextualize information gathered through interviews and policy observations; and second, to add to the study information that would not be appropriate or feasible to collect through interviews or observations, either because of the political sensitivities of the topics or time constraints.

This chapter addresses the following research questions:

- How can the three countries ensure that their national safeguards frameworks address all the potential REDD+ social and environmental risks while at the same time taking into account national sovereignty and legal contexts?
- What factors should the three countries take into account to establish effective, efficient and equitable national REDD+ grievance mechanisms?
- To what extent do stakeholders in the three countries consider REDD+ as a mechanism that will help contribute to empowering forest-dependent communities to exert a greater influence on local land use policy and practice?

Given the focus of this chapter, the main research sites for the three countries were located within government ministries that are tasked to develop the national REDD+ strategy. This approach is unlike traditional research where a research site is often located in a province or a village. The line agencies, or our objects of analysis, responsible for the development of REDD+ strategies within their respective countries and formed the focus of the research effort were: the Forestry Administration (FA) of the Ministry of Agriculture, Forestry and Fisheries (MAFF), Cambodia; the Forestry Department (FD) of the Ministry of Environmental Conservation and Forestry (MOECAF), Myanmar; and the Department of National Parks and Wildlife Conservation (DNP) of the Ministry of Natural Resources and Environment (MONRE), Thailand. The research teams also collected data from provinces where REDD+ would potentially be implemented. For example, data collection was undertaken in

Mondulkiri and Oddar Meanchey provinces in Cambodia; four villages in Myanmar, including Lat Maung Kwe, Lwe Nyeint, Kan Taw, and Myay Char; and data collection in Muang Ang village, Chiang Mai province in northern Thailand.

Data collection

Step 1: Stakeholder identification

We defined a stakeholder as an individual or a group who is affected by, or can affect, the realization of national REDD+ policies in Cambodia, Myanmar and Thailand. To identify stakeholders, the procedure started with the research team in the three countries reviewing (1) REDD+ national policy documents, in particular the Readiness Preparation Plan (R-PP) submitted to the FCPF and/ or UN-REDD Programme; grant agreements subsequently approved by the World Bank (or equivalent documents of other FCPF Delivery Partners) under the FCPF; and National Programme Documents subsequently approved by the participating UN Agencies under the UN-REDD Programme; (2) REDD+ feasibility studies conducted by different organizations; (3) newspaper articles, radio broadcasts; and (4) suggestions from in-country REDD+ experts on who to include as stakeholders. Stakeholders were grouped into three levels (international, national, and local) to correspond with their engagements in the REDD+ policy processes in the three countries. We further categorized stakeholders in these three levels into: (1) governmental bodies, (2) non-governmental organizations, (3) indigenous peoples/ local groups, (4) the private sector, and (5) academic/ research institutions. These categories are both descriptive and analytical. As alluded to in previous studies (Clark et al. 2001, Bebbington and Bury 2009), stakeholders' responses and participations in REDD+ readiness process vary according to their different organizational locations. We used Nvivo 10 to construct the stakeholder list and to store the information specified above in a metafile.[2]

Step 2: Key informant interviews

The research team in each country conducted up to 50 in-person, semi-structured interviews with the different groups of stakeholders. The interviews were between 45 to 60 minutes long, and were conducted in local languages (where possible), national languages, or English. To select interview participants, the research team in each country relied on the list of stakeholders identified through the sources and activities previously mentioned. The research team ensured that interviewees were drawn from representatives of the five categories of stakeholders described above. Interview questions solicited information on:

- stakeholders' general demographic, academic or professional backgrounds, understandings of REDD+ policies in general and in Cambodia, Myanmar and Thailand (e.g. objectives, institutional arrangements, other stakeholders);
- their comments on their own engagements, and those of other stakeholders, with REDD+ policy dialogues (for example: participation in different meetings, consultations, training events, workshops, conferences);
- modes of engagement (or lack thereof) with REDD+ policies and their development in the three countries;
- how safeguard policies and measures should be developed and implemented;
- how grievances from REDD+ should be managed; and
- how REDD+ could assist in empowering local stakeholders to exert a greater influence on local land use policy and practice.

Step 3: Participant observations

Additional to compiling individual accounts, empirical observation on how the different groups of stakeholders engage in REDD+ policy dialogues/ processes were required to understand how stakeholders engaged in these processes. With permission from key institutions responsible for convening the policy dialogue processes on REDD+, members of the research team in each country attended major meetings conducted by the national REDD+ coordination and implementation arrangements establish to facilitate the development and implementation of REDD+ policies in Cambodia, Myanmar and Thailand. These arrangements in general include: the National Climate Change Committee; REDD+ Advisory Group; REDD+ Taskforce; REDD+ Taskforce Secretariat; and the Technical Teams and/ or Working Groups. The research team took extensive written notes of these meetings. Data collected from these observations enabled the research team to analyze the social challenges, which included issues such as participation, problem framing, scale and timing of information, and management of alternative sources of information.

Step 4: Archival research

The teams from each country conducted archival research to validate, compare, and contextualize information gathered through key informant interviews and participant observation. The team examined relevant government policy documents, reports and feasibility studies conducted by research institutions and private firms, reports from non-governmental organizations and mass media outlets, many of which were otherwise inaccessible without being in Cambodia, Myanmar and Thailand. Variables to which the research team paid particular attention during archival research include: history of deforestation and forest/ land uses, social arrangements (in particular stakeholders' access to land, forest and carbon rights), ecological settings, and physical accessibility in the three countries. Data pertaining to these variables added to the study information that would not be appropriate or feasible to collect through interviews or observations, either because of the political sensitivities of the topics or time constraints. Without this specific information, the team would not be able to establish reference points from which to analyze the extent to which information—discussed in the REDD+ policy processes—took into consideration contexts that were salient, credible and/ or legitimate for the different groups of stakeholders in three countries.

Data analysis

Throughout the data collection period, the research team maintained a daily journal in which they recorded their observations, impressions, questions needing follow-up, and key patterns they saw emerging. Data from interviews were transcribed and then coded using Nvivo 10. Notes from observations and archival data were also imported into Nvivo 10. Data were classified according to the location within the three countries and coded for each stakeholder. Initially, Nvivo's Word Frequency and Text Search queries were used to explore the data—first specific to country locations and stakeholders' groups. These queries produced a series of open themes that were used for subsequent coding activities (Bazeley

2007). King and Horrocks (2010) defined themes as the recurrent and distinctive features of participants' accounts, characterizing particular perceptions and/ or experiences. We used thematic content analysis to develop codes, interpret their meaning and inter-relationships, and to develop analytic themes that iterate with and extend the research question in the three countries.

We organized our themes according to the keywords from our research questions and the data collected from the three countries. For example, notes from the field are organized under these headings, themes or keywords: safeguards, contexts, effectiveness, efficiency, equity, empowerment, tenure, national strategy, Cambodia, Thailand and Myanmar. Other analytical themes emerged through the course of research that included: stakeholders' participation at the three scales of policy dialogues—international, national, and local; local conditions/ contexts—social, ecological, economic, and political; criteria for assessing REDD+ policies in general; criteria to consider in developing a safeguards framework; grievance mechanisms; local communities' land use norms and practices. Descriptive coding was further developed through a process of memo-writing to establish analytic themes, short statements that describe the interactions among the different concepts. By coding our data individually, we were able to use Nvivo's Matrix Coding queries to summarize the empirical data for each participant in our five stakeholder groups, specific to the country, to generate a list of various criteria that the different groups provided in response to the three research questions (Bazeley 2007).

Results

Guided by the main research objective, the following sub-sections present findings on the extent to which state and non-state stakeholders in Cambodia, Myanmar and Thailand were engaged/disengaged in the processes to develop the national REDD + strategy (NRS). As discussed earlier, the NRS is one of the four required elements for a country to be eligible to access results-based payments (RBP) as it describes how emissions would be reduced and/or forest carbon stocks enhanced, conserved and/or sustainably managed via the implementation of REDD+ policies and measures (UNFCCC 2010, 2013, 2015). The UNFCCC did not adopt any specific technical guidance on the template nor content of the

NRS for a country to follow. In other words, it is up to the countries to decide on the content of and process to develop their NRS. Furthermore, it is important to note that the NRS would not need to be technically assessed nor endorsed by the UNFCCC. As stated in Decision 11 of the Warsaw Framework for REDD+, countries are only required to publish a link to their NRS on the Information Hub of the UNFCCC's REDD+ Web Platform to be able to receive results-based payment (UNFCCC 2013).

Cambodia National REDD+ Strategy

Development of the Cambodia's NRS was one of the four main components of the REDD+ Readiness Roadmap, the UN-REDD Cambodia National Programme and the World Bank's FCPF Project Document (RGC 2011, 2013). As mentioned in the introduction, the four required components from all REDD+ countries include NRS, FREL, SIS and NFMS. Officially, the process to develop the NRS started at the fourth National REDD+ Taskforce (TF) meeting, organized in March 2014, where members approved the request of the REDD+ Taskforce Secretariat (RTS) to start the NRS drafting process. The skeleton of the NRS and a document describing the workplan and methodology to develop the first working draft of the NRS was produced in August 2014. The first draft of Cambodia's NRS was completed in December 2014. The first draft was presented to the TF's members during their sixth meeting, held at the end of December 2014. Given that the NRS would be applicable for the entire nation of Cambodia, the TF decided that it was essential that all relevant stakeholders are given ample opportunity to review and provide their comments on the NRS working draft. The goal was to ensure that government and non-government stakeholders' perspectives would be adequately incorporated into the final draft of the NRS and to encourage their participation when the NRS is implemented (RTS 2014). After this meeting, the RTS developed a roadmap to guide consultation on the NRS working draft before its finalization.

Table 5.1 presents the key dates of the consultation processes conducted to develop the NRS, whereas fig. 5.1 summarizes the consultation roadmap. As presented in table 5.1, a series of consultations with relevant stakeholders were organized for eleven months from January to November 2015 to gather their comments before the NRS working draft was finalized. Relevant stakeholders were not limited to but included the members of the TF, Consultation Group (CG), Gender Group

(GG), Technical Teams (TT), local communities, Indigenous Peoples, international and national NGOs, the private sector and government authorities at local, provincial and national level. Furthermore, as illustrated in fig. 5.1, the fourth working draft of the NRS was extensively consulted with stakeholders at the sub-national level, which included government officials, local communities, Indigenous Peoples, NGOs and women. These stakeholders were additional to the TF, TT, CG, GG members. Figure 5.2 reveals the institutional affiliations of stakeholders consulted at the sub-national level. In total more than 1,000 people were consulted.

After the four sub-national consultative meetings, the four national consultants conducted a series of meetings with senior government officials from the FA, Ministry of Environment (MoE) and Fisheries Administration (FiA) on the fourth working draft of the NRS in October 2015. Additionally, the Cambodia CSO-REDD+ Network organized a one-day consultation with their 53 members to review and provide comment on the fourth working draft. Their comments were sent to the RTS. Comments from all of these consultation activities were then incorporated into the NRS fifth working draft, which would be presented to relevant stakeholders at a National Validation Workshop, to be held on November 19, 2015, in Phnom Penh city. The final draft of the NRS would then be revised based on comments received from all the stakeholders mentioned above. Despite the approved plan, the national workshop did not take place given the limited time and other administrative constraints, and the fifth working draft was produced in early November 2015.

Once this draft was produced, it went through a series of discussions at FA. The sixth working draft was developed by late November 2015. The final working draft of the NRS was presented at COP21 of the UNFCCC in Paris, France. Given the number of stakeholders consulted and the comments received, achieving consensus was the means used to decide on technical, procedural topics where comments varied. Overall, the process was open, inclusive and transparent. The final draft of the NRS did capture much of the comments raised during these consultative meetings. A background document that detailed these consultative processes was also developed (Nguon and Chhun 2015) to note all comments received, as well as those that were used in the final draft of the national strategy and those that were not provided with justifications.

Table 5.1. Cambodia: Consultation processes conducted to develop the National REDD+ Strategy (NRS)

Working Draft of the NRS	Dates
TF Approved the RTS to Start NRS Development	March 14, 2014
TF Approved Proposed Chapters	June 10, 2014
Work Plan and Methodology	July 31, 2014
Skeleton	August 31, 2014
Initial Working Draft	December 31, 2014
Consultations with Expert Team Members	January 2015
Second Working Draft/ Background Document	April 10, 2015
First Consultative Meeting with TF, TTs, CG, GG	May 20–21, 2015
Third Working Draft/ Background Document	June 10, 2015
Second Consultative Meeting with TF, TTs, CG, GG	July 6–8, 2015
Fourth Working Draft/ Background Document	21 August 2015
Four Subnational Consultative Meetings Kratie province Sihanouk Ville province Battambang province Siem Reap province Audience (government and non-government officials at provincial level, local communities and indigenous peoples)	 September 8–9, 2015 September 15–16, 2015 September 22–23, 2015 September 29–30, 2015
Consultations with key government officials Forestry Administration Ministry of Environment Fisheries Administration	 October 5, 2015 October 19, 2015 October 28, 2015
Fifth Working Draft/ Background Document	November 6, 2015
National Validation Meeting/ Phnom Penh Audience (government and non-government officials at national level, development partners, TF, TTs, CG and GG)	November 19, 2015 DID NOT TAKE PLACE
Final Working Draft/ Background Document	November 25, 2015
Presentation/ Promotion of NRS at COP21	December 1, 2015
Endorsement by MAFF/ MoE/ PM	Pending

Figure 5.1. Cambodia: Consultation roadmap of the NRS working drafts

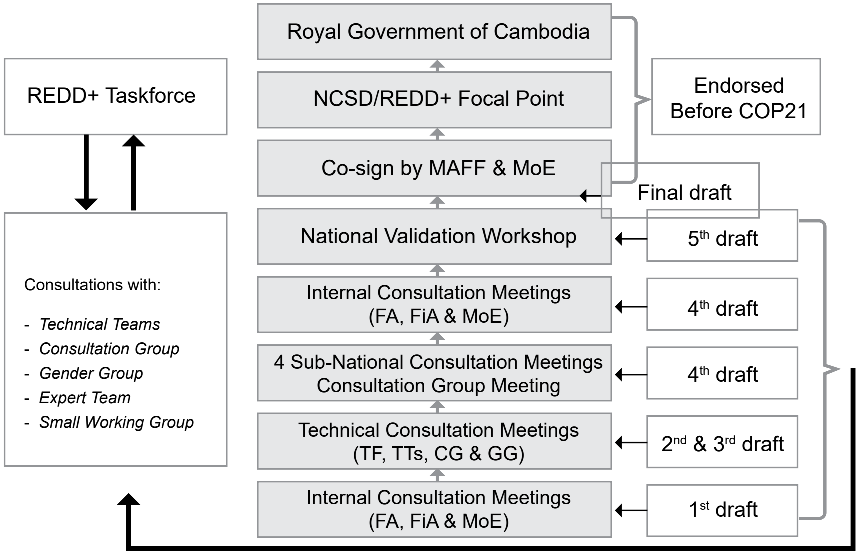
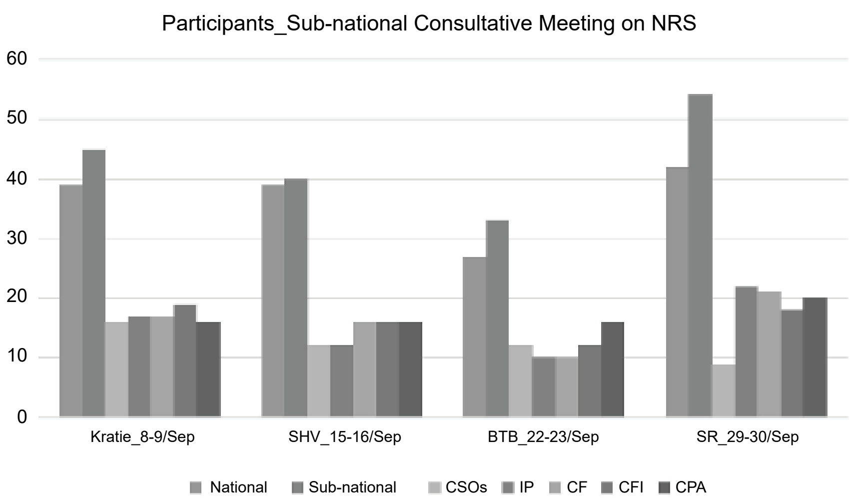


Figure 5.2. Stakeholders consulted to each sub-national meeting



Myanmar National REDD+ Strategy

Unlike Cambodia, the process of developing a Myanmar national REDD+ strategy is still at an early stage. At the time of writing, the Government of Myanmar had conducted studies that resulted in the development of a range of policy documents that will form the fundamental inputs for the development of the national REDD+ strategy. These included the national approach to REDD+ safeguards and initial draft of the Myanmar national REDD+ grievance mechanism. A discussion of these elements is presented below.

Myanmar recognizes the potential of the REDD+ initiative to contribute to green development by protecting global environmental resources (forest carbon stocks, but also biodiversity), helping to reverse land degradation, contributing to improved livelihoods of the rural poor and aiding adaptation to climate change (Government of Myanmar 2013). Myanmar became a partner country of the UN-REDD Programme in December 2011 and has quickly taken steps to start implementing REDD+ readiness activities. This Roadmap, divided into six components, sets out how Myanmar will implement its REDD+ Readiness activities. Myanmar is currently working on its National REDD+ Strategy as well as the other required components (SIS, FREL and NFMS) as stated in the Warsaw Framework for REDD+ (ibid.).

Although the National Action Plan is stated as a separate component, it not only considers how to mitigate and/ rehabilitate deforestation and forest degradation, but it also includes the actions that can support the above three components. Therefore, preparing the other three components can also be considered preparation for the National Action Plan.

According to the National REDD+ programme director, the first draft of the strategy will be completed by the end of 2016 and a comprehensive consultation process will be implemented to discuss the various drafts with the plan to have a final draft by the end of 2017. Interviews with relevant policymakers indicated that development of the Myanmar national approach to REDD+ safeguards has been an important vehicle to promote understanding of REDD+ among stakeholders given that the initiative is a new concept in Myanmar. Based on their interpretation of the Cancun Agreement (UNFCCC 2010), Myanmar defined several social and environmental safeguards under the UNFCCC in order to avoid risks related to the implementation of REDD+. For example, following their interpretation of the Cancun safeguards, the FD developed the basic framework for REDD+ social and environmental safeguards under the International Tropical Timber Organization (ITTO) project.[3] A member of the focal REDD+ core unit explained that the "establishment of country safeguards system will include the development of a transparent information and monitoring system. The validation of the proposed safeguards system is at an early stage of consultation with and approval from relevant stakeholders through national consultation process,"[4] and another added that this would be "with the collaboration of ADB."[5] However, one interviewee pointed out that "cohesion of safeguards is still weak and has requirements for considering the rights of ethnic nationalities."[6] Another stakeholder explained that "the FD understand and are aware that all actions in REDD+ not only have to be in line with the Sustainable Forest Management and Timber Certification by FD but also not to conflict with UN conventions such as UNFCCC and UNCCD."[7]

Myanmar is fully aware of and accepts the fact that REDD+ activities could not be achieved without the active participation of local communities as well as good governance with transparency and accountability. It is undeniable that a range of human rights improvements have accompanied the political reform process. In addition, Resolution 10/4 of the United Nations Human Rights Council on Human Rights and Climate Change (March 2009) emphasizes that all climate change related activities should fully respect human rights. It is also in line with Constitution of the Republic of the Union of Myanmar, Section 347, which states that: "The Union shall guarantee any person to enjoy equal rights before the law and shall equally provide legal protection," and Section 348, "The Union shall not discriminate any citizen of the Republic of the Union of Myanmar, based on race, birth, religion, official position, status, culture, sex and wealth." However, some argue that it might be difficult to reflect all human rights in the REDD+ mechanism. In fact, it will be the best to adopt international best practice obligations and safeguards that are consistent with country situations such as those of the World Bank's Environmental Social Framework and the Green Climate Fund. They should also include appropriate risk management systems to prevent and address adverse impacts on human rights and legitimate tenure rights. One interviewee asserted that "people are the owners of the forests. Therefore, they should have the right to be involved in the management and enjoy legitimate use of the national forests, their own rights of provisions, rights over land and natural resources, and should be informed of development activities such as REDD+ on their own lands by Free, Prior and Informed Consent (FPIC)."[8]

Based on the knowledge, understanding, skills and attitude of key stakeholders from government bodies, nongovernmental organizations, representatives of indigenous peoples, academic institutes, it seems that Myanmar still has a long way to go to develop its national REDD+ safeguards information system. However, Myanmar is practicing its own standards of REDD+ safeguards by using pre-existing legislation or enacting new laws which reflect international conventions and agreements. The constraint is that these new developments are not necessarily in line with the decision texts from the UNFCCC regarding REDD+ safeguards; and thus, policy harmonization has been one of the key tasks for Myanmar as well as countries such as Cambodia and Thailand.

In addition, another challenge for Myanmar to develop its national REDD+ strategy is that the government has been focusing more on project-based, voluntary carbon market REDD+ initiatives funded by multilateral and bilateral institutions rather than the UNFCCC national REDD+ strategy, citing the uncertainty of secure and long-term finance. Some interviewees mentioned that Myanmar's participation in project-based REDD+ while simultaneously pursuing the UNFCCC national approach is a disadvantage because the projects have different technical and procedural requirements which do not necessarily favor a rights-based approach. This may hinder the efforts of "fragile" countries such as Myanmar in ensuring that its safeguards policy addresses and respects the Cancun safeguards. In addition, the recent rapid democratic reforms in every sector in Myanmar to some extent bring both challenges and opportunities for the effective implementation of REDD+. Nevertheless, Myanmar still has to strike a balance between economic development and environmental conservation through implementation of strategies such as REDD+. Under these situations, instead of providing financial incentives as "rewards" based on results, interviewees suggested that Myanmar should "invest" based on performance in development and implementation of new policies and reforms because it would be compliant with the UNFCCC requirements.

Thailand National REDD+ Strategy

Among the three countries, Thailand was the first country to participate in the FCPF. However, there has not been any progress in the development and implementation of REDD+ in Thailand. This is evidenced in the last report of the Royal Government of Thailand (RGT) that was submitted to the FCPF dated May 2014, announcing that the national REDD+ process had been put on hold since March 2013 (RGT 2014). Therefore, our focus on observing the process of REDD+ in Thailand did not focus on the development of Thailand national REDD+ strategy, rather we documented some of the work that has been undertaken in Thailand as preparation for the national REDD+ strategy if it is to be developed in the future. There has been progress to develop a national approach to REDD+ safeguards in Thailand as a preparation for the national REDD+ strategy. In the following section, we reported on the FCPF progress in Thailand up until May 2014 followed by some observations on the development of the national approach to REDD+ safeguards in Thailand highlighting concerns from stakeholders.

In 2010, Thailand decided to participate in the REDD+ partnership and established a REDD+ TF in 2011 as an inter-ministerial and multi-sectoral committee. The REDD+ TF in Thailand is currently chaired by the director general of the Department of National Parks, Wildlife and Plant Conservation (DNP) and includes representatives from key government agencies that contribute to studies on deforestation and forest degradation (RGT 2011). In 2013, the REDD+ TF was strengthened by revising the composition of committee members and including a larger number of stakeholders, including representatives of government and non-government agencies, NGOs, local forest-dependent communities, private sector organizations, academia and research institutions. In an interview with the REDD+ national focal point group, each representative was nominated by the respective institution through a self-selection process.

The need for a multi-sectoral approach to REDD+ implementation is critical as the drivers of deforestation and forest degradation often lie outside the forestry sector. Therefore, for REDD+ to be implemented in an inclusive and participatory manner, it requires an institutional arrangement/management structure that reflects the relevant sectors engaged in land use and other stakeholders with an interest and stake in REDD+. Thailand completed and submitted its Readiness Preparation

Plan (R-PP) document to FCPF in 2013. The PCFP later approved the proposed document. However, Thailand has not started implementing its R-PP phase as it is still under the consideration of the Cabinet. Under the current political situation it is not clear how long the approval process will take. To put this slow REDD+ development into a broader, longer perspective, one should understand the history of forest management in Thailand.

Since the early 1990s, the government of Thailand has attempted to resolve conflicts between the state and forest-dependent communities. The Royal Forest Department (RFD) initiated a program on Community Forestry to promote the participation of local people in managing and conserving forest resources in close proximity to their villages. At present, there are more than 9,000 forest-dependent communities registered within the Community Forest Program. Under the program, local people were permitted to collect forest products to sustain their livelihoods. Through the program, confrontation between forest officials and forest-dependent communities declined significantly although the program was restricted to local communities who reside outside protected areas, thereby excluding local communities who live inside protected areas. These communities are not able to register their forest as official community forests, hence their activities in the forest area are considered illegal.

In Thailand, stakeholders agreed that the international REDD+ initiative could have both positive and negative impacts. Interviewees mentioned that the potential positive impacts would include improved alternative livelihoods, greater biodiversity due to an increase in forest cover, and stronger natural resource management networks. However, many stakeholders highlighted their concerns about implementing REDD+. Local NGOs and community representatives feared that REDD+ implementation would harm the livelihoods of forest communities who live in protected areas, in particular, the ethnic minority groups who practice shifting cultivation. These ethnic groups have no legal rights to the land they occupied but claim land and resource access within protected areas by referring to their customary rights. If the REDD+ program is imposed in these areas, local communities and livelihood practices would be threatened without proper social and environmental impact assessments including FPIC, because they do not technically own the land.

To address the potential negative impacts of the legality of settlement status (an issue that is common to both Cambodia and Myanmar), Thailand has developed a national approach to REDD+ safeguards rather than pursuing parallel voluntary carbon market REDD+ safeguards. Stakeholders considered the safeguards an important tool in minimizing risks and helping to improve the level of services that REDD+ could deliver in the near future. In Thailand, the national approach to REDD+ safeguards was prepared and developed through stakeholder consultation processes. However, due to a limited understanding of the technical details of REDD+, it is noted that forest-dependent communities faced challenges with regards to their participation in the REDD+ consultative process. As a result, interviewees suggested that given the limited understanding of the safeguard concept among different stakeholder groups, extensive capacity development at all levels is essential in developing and implementing REDD+.

Approaches to this capacity building should be participatory and pro-poor, given that the implementation of REDD+ activities will most likely be in areas where there are a lot of poor communities and indigenous people. Stakeholders will need to develop new knowledge, skills, and expertise in order to effectively design, develop, implement, and monitor REDD+. The capacity of government forest agencies, civil society organizations, and local communities will need to be strengthened. Local level forest protection measures will need to be improved, along with the knowledge and capacity of national and local forest protection and law enforcement agencies, so they can effectively enforce forest protection laws. Systems for monitoring, reporting, and verifying changes in forest carbon stocks at the local level will need to be developed. It would be impractical to try to raise the awareness of all relevant stakeholders, all over the country. Thus, the decision on how capacity should be built needs to be framed in the context of Thailand having to, first, assess its drivers and then design policies and measures that will address these drivers. Safeguards will need to be put in place to protect people and the environment from being harmed by these policies and measures.

Discussion and policy implications

Our analyses of the development of national REDD+ strategies in the three countries pointed to five key observations. First, it has been almost ten years since Cambodia, Myanmar and Thailand embarked on the notion of implementing REDD+ as a means to reduce emissions. Once this decision was announced by the national REDD+ focal points to the UNFCCC, all three countries submitted their Readiness Plan Idea Notes [R-PIN] to the World Bank's FCPF and the UN-REDD Program. All three countries developed their national REDD+ Readiness Roadmaps to guide the development and implementation of the UN-REDD Programme and/or the FCPF. One of key outcomes for the UN-REDD Programme and FCPF's support is the development of a national REDD+ strategy. While Cambodia has tentatively produced its draft national REDD+ strategy and presented the draft at the UNFCCC meeting in 2015 in Paris, technically all three countries have yet to have a national REDD+ strategy that is adopted or endorsed by their respective national governments. This study highlights the uncertainty that the national REDD+ strategy will be developed in Thailand.

A national REDD+ strategy is essentially a national document which details the policies and measures that a country will implement to reduce emissions from select drivers of deforestation and forest degradation. According to the UNFCCC decisions, it is expected that countries supported by the UN-REDD Programme and/or the World Bank should have their national REDD+ strategy developed by the end of their REDD+ readiness phase. However, the process of developing a national REDD+ strategy is fraught with challenges, most of which are political in nature due to the fact that stakeholders involved in the process have different concerns and interests. While not exhaustive, the development of the national REDD+ strategy in the three countries along with its key components revealed the following concerns:

a. Concerns for government stakeholders

- Political and socioeconomic implications of drivers of deforestation and forest degradation to be addressed
- Political and socioeconomic impacts of policies and measures to be implemented

- Institutional arrangements to oversee implementation including decisions on the design of the incentive allocation systems

b. Concerns for non-government stakeholders

- Impacts of the national REDD+ strategy on their ongoing or planned activities, most importantly if their activities involved project-based REDD+
- Participation in the process to decide on key national REDD+ strategy aspects such as drivers of deforestation and forest degradation, policies and measures, safeguards, and implementation frameworks

c. Concern for local communities and indigenous peoples

- Impacts of the REDD+ policies and measures on their daily routines and livelihood, in particular for those who depend on forest resources.

While the national REDD+ Roadmap was finalized in 2010 for Cambodia, Thailand and Myanmar, its implementation did not start as planned for all three countries. Implementation of the Cambodia REDD+ Roadmap did not start until 2013; while the timing and implementation of the roadmap for Thailand remains uncertain given the broader political fluctuations.

The reasons for the delay were attributable to a combination of factors that included: institutional capacity constraints for both government and development partners involved in the process, REDD+ complexity, poor sequencing and implementation of activities, the bureaucracy in United Nations agencies, the FCPF and the government institutions. To achieve suitable sequencing of readiness activities while taking into account the national context, a comprehensive capacity needs assessment should be conducted to assess potential constraints and enabling factors in institutions to implement the activities. Results from this assessment could be used to determine more realistic timeframes that a country would require to complete the readiness phase. The allocated timeframe for the completion of the readiness phase and development of the national REDD+ strategy was insufficient for Cambodia, Thailand and Myanmar. Furthermore, given the range of support and institutions claiming to contribute to a national process in the three countries, resulting in unnecessary confusion about REDD+ as in the case of Cambodia, the government should develop a national and sub-national capacity-building plan for REDD+ so that supporting frameworks could be channeled and aligned with them. Such plans could outline results of a needs assessment, expected objectives, action plans, funding needs and monitoring and evaluation framework. The governance of REDD+ Readiness phase and the process of developing a national REDD+ strategy in the three countries indicated that while REDD+ might be a simple concept, realizing it requires a strategic balancing act between the excessively complex configurations of stakeholders, interests and politics and the complex technical guidelines, processes, frameworks and methodologies.

In this context, this research argues that effective boundary work performed via boundary agents does contribute to stakeholders' perceptions of the national REDD+ strategy as salient, credible and legitimate. Mainly, boundary agents facilitate communication, translation and mediation of the different political and personal interests that stakeholders bring into the process of drafting the national REDD+ strategy (Nguon 2018). This research concludes that successful development and implementation of the national REDD+ strategy in the three countries would require policy coherence across sectors that have jurisdiction over forest and land resources, accountability and participation from government and non-government stakeholders from local to national level. Opportunities for meaningful dialogues across sectors should help alter the embedded institutional path dependencies and prevailing power structures that drive deforestation and forest degradation. Finally, the positive or negative impacts of the national REDD+ strategy in the three countries will be gradual and should be judged in terms of its abilities: to change the norms, values, and power structures that support current trajectories; to garner credible commitments to reform the forest-related sectors; and to create meaningful cross-sectoral dialogues in support of the national strategy.

Conclusion and lessons learned

We provide some lessons learned from our observations that might be relevant for countries that are in the process of developing their national REDD+ strategy or about to start the process. First, activities that produce important technical inputs for the national strategy such as assessment of drivers of deforestation and forest degradation must be implemented at the earliest stage of the REDD+ readiness process. For example, most of these sources of information were not readily available in Cambodia despite the fact that the readiness activities were already at their end. This made drafting the national REDD+ strategy particularly challenging since decisions on various crucial issues were made without full technical knowledge.

Second, given that the development of a national REDD+ strategy is a lengthy process with different stakeholders engaged in the various working drafts, it is important to keep track of decisions made at each step. For example, the Cambodia's NRS Background Documents served as a reference point for old and new stakeholders involved in the drafting process.

Third, it is crucial to note not only that REDD+ is just one of the means to address climate change, but also that a truly transformative national REDD+ strategy will generate opposition from potentially powerful sectors that drive the national economy. Thus, the success of the strategy will depend largely on national government commitment to modify business-as-usual practices. At the same time, the key challenge for the strategy proponents would be to build a convincing cost-benefit analysis of the impacts of policies and measures on the national economy. Finally, there is a possibility that a national REDD+ strategy would become yet another *unimplementable* policy document (Mosse 2004) due to the political and economic pressures from stakeholders both within and outside of the forest sector. If that is the case, a properly designed national strategy development phase will help a participating country to establish or strengthen its NFMS, and to identify drivers of deforestation and forest degradation, as well as the challenges to address them and to understand the links between forest-related and other sectors.

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Notes

1 UNFCCC Conference of the Parties, Decision 1/ CP.16. Par. 70 (2010).
2 See http://www.qsrinternational.com/nvivo/support-overview/downloads/nvivo-10-for-windows.
3 Interview with U Pyae Soe Aung, REDD+ TWG, FD, July 10, 2015. Naypyitaw.
4 Interview with U Bo Ni, focal REDD+ Core Unit, July 11, 2015. Naypyitaw.
5 Interview with Daw Naw Ei Ei Min, Director, Promotion of Indigenous and Nature Together, November 26, 2015, Yangon.
6 Interview with U Shwe Thein, Chairperson, Land Core Group, July 10, 2015. Yangon.
7 Interview with U Sein Thet, Project Coordinator, ITTO REDD+ Project, August 8, 2015, Naypyitaw.
8 Interview with Dr Rosy Nay Win, Assistance Director, MNREC, November 12, 2015, Naypyitaw.

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6

Rural households and climate change adaptation: Lessons from Cambodia and the Philippines

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Cambodia and the Philippines have been subject to increasingly frequent extreme weather events such as typhoons, as well as floods and droughts, which cause severe losses and damage to crops, property and livelihoods. This chapter explores the adaptation decisions of rural households and communities affected by climate-related hazards; tracks and examines their adaptation strategies; and analyzes if these are building the community's climate resilience.

The Intergovernmental Panel on Climate Change's *Fifth Assessment Report* (IPCC 2014) observes that many changes in the climate system, such as more extreme temperatures and rising sea levels, are unprecedented and linked to human influence. More frequent and longer heatwaves as well as more intense and frequent rainfall are very likely in various parts of Asia (ibid.).

Climate change is already evident in Southeast Asia, with mean temperature increases between 0.14°C and 0.32°C per decade between 1951 to 2000 (IPCC 2007). With millions of Southeast Asians still trapped in poverty, and their largely rural livelihoods highly climate-sensitive, the region is one of the most vulnerable to climate change. Meanwhile, deforestation and land degradation have significantly contributed to greenhouse gas emissions in the region between 1990 and 2010 (Raitzer et al. 2015).

The impacts of climate change in Southeast Asia are projected to slow down economic growth, affect water availability, erode food security, reduce income, and hinder poverty alleviation programs. Climate-related economic losses have implications on production levels, the environment, human vulnerability, and livelihood sustainability. These have consequential effects on income reduction and poverty incidence; and even on depleting savings and disrupting investments necessary to provide employment and improve incomes (UNDP 2004). The impact of global climate change and natural disasters is greatest at the local level, hampering efforts to address poverty (UNISDR 2012).

Asia has a long history of droughts and other climate extremes that have severe impacts on its least developed economies. Asian monsoon regions feed half of the world's population and during droughts, 23 million ha of rice experience yield loss. At the other extreme, floods are said to be becoming more frequent in Asia, including in the Mekong Region and the Philippines (Loo et al. 2015).

In Cambodia, drought has been the most severe weather hazard in most provinces, increasing in intensity and frequency since 2000 (Miyan 2015). The Philippines ranked highest in vulnerability to tropical cyclones, averaging 20 per year and third in terms of people's exposure (UNDP 2004).

The Royal Government of Cambodia (RGC) established a climate change adaptation policy and framework in 2006, increasing the roles and responsibilities of institutions from national to local levels to implement adaptation programs (RGC 2006; CDRI 2012; Sreng 2013). Even so, policy implementation and interventions at the local level have remained limited and ineffective. Responses to extreme weather events and natural hazards have been ad hoc and thus are not sustainable. National adaptation strategies focused on hard strategies such as infrastructure rebuilding, but key contributing issues such as deforestation, the destruction of catchment areas, and water pollution have not been satisfactorily addressed (UNCDF 2013). Similarly, the Philippines formulated its National Framework Strategy on Climate Change for 2010–2022. It highlights the critical role of adaptation at all levels of governance, with the local government as frontliners.

An important consideration for adaptation policy is its contribution to climate-resilient and sustainable development. Climate-compatible development emphasizes strategies that safeguard development (including poverty reduction and human development) from climate impacts (Mitchell and Maxwell 2010). Inadequate adaptation responses to the changing climate are eroding the basis for sustainable development.

Adaptation strategies that take a long-term perspective will enhance future options and preparedness and address sustainable development (IPCC 2014). Capacity building for adaptation should take place at three levels—national, community and household.

This study focuses on household-level adaptation, but recognizes that social capital plays a critical role in a community. The analysis of household adaptation aims to provide a view that better reflects their positioning and role(s) in broader social–institutional contexts, or within a larger governance context. For example, the policy setting, the socio-cultural context, and other factors may influence or hinder household adaptation actions. A household is therefore one element within a larger, complex system of policies and institutions that influences vulnerability to hazards that arise from climate change (Elrick-Barr et al. 2014).

Cambodia and the Philippines were selected as comparative country cases because both have finalized their national climate change adaptation frameworks, with a focus on the role of local government. However, actual implementation varies at the local level. This chapter looks at study areas in Cambodia and the Philippines (fig. 6.1) to discern the key reasons why these local outcomes are different.

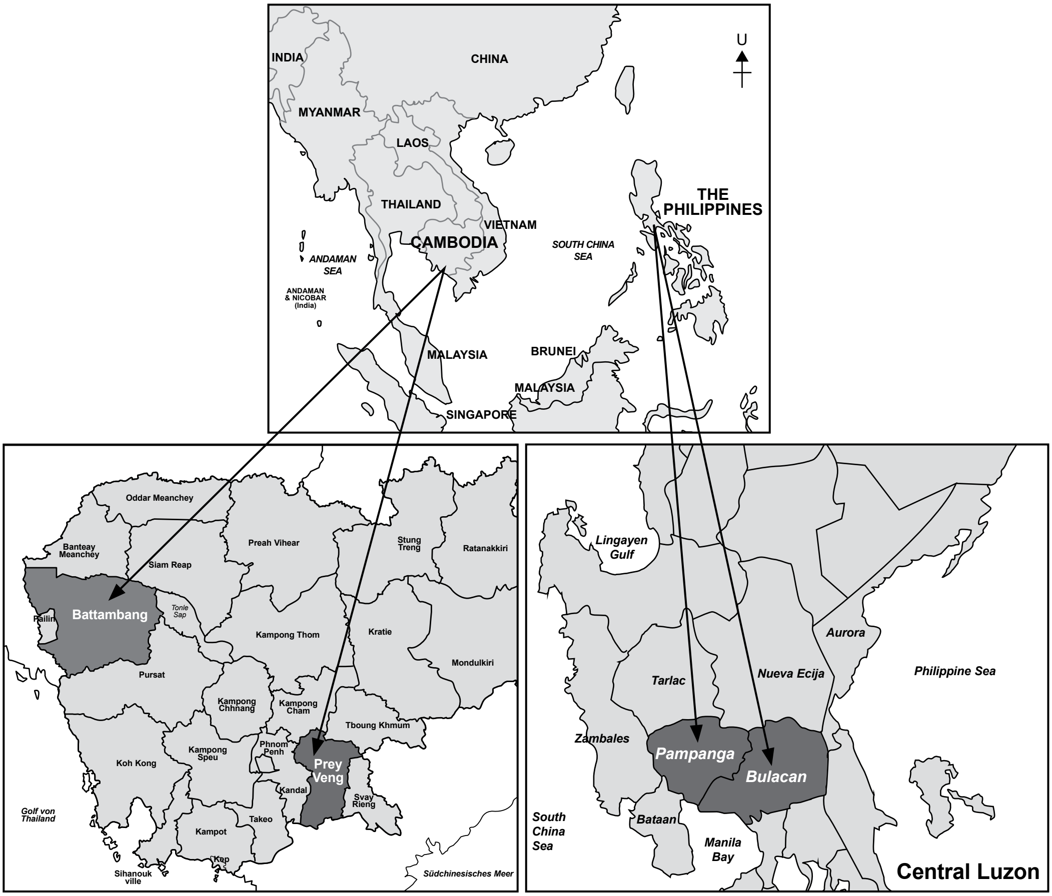
With particular focus on selected rural communities in Cambodia and the Philippines, this chapter addresses the following research questions: 1. What are the adaptation decisions of rural households and communities frequently affected by climate-related hazards? 2. Are these adaptation strategies building household resilience? 3. Are these adaptation strategies contributing to community-level climate resilience?

Conceptual framework

Adaptation, in the context of our study, refers to adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects that moderate harm or exploit beneficial opportunities (IPCC 2007). It aims to moderate, cope with, as well as take advantage of the consequences of climate events. Adaptation is both temporal and spatial. Strategies may be short or long term; and they may be localized or cover a wide area.

Adaptation measures may be categorized as reactive, anticipatory or proactive; autonomous, and planned (Fankhauser et al. 1999; ICCG

Figure 6.1. Location of study areas in the Mekong Region and the Philippines



Sources: https://commons.wikimedia.org/wiki/File:Map_of_Southeast_Asia.png; https://commons.wikimedia.org/wiki/File:Central_Luzon_Map.png; https://en.wikipedia.org/wiki/Geography_of_Cambodia.

2014). Reactive adaptation is in response to climate change, after the fact. Anticipatory or proactive adaptation measures are those that are deliberately implemented before climate change is observed and requires foresight and planning. For example, responding to current and past flood events may be considered reactive, while an early warning system and acting before a flood is anticipatory adaptation (ICCG 2014).

Adaptation may also be classified as autonomous, that is, natural or spontaneous, while planned adaptation is a proactive, conscious or deliberate response (Fankhauser et al. 1999; ICCG 2014). Autonomous adaptation is triggered by changes in natural systems and market or welfare changes in human systems and relies on available knowledge and techniques (Malik et al. 2010). It is based on awareness of changing conditions and understanding that action is required. It means the use of information on present and future climate change, a review of suitability of current and planned practices; and consideration of other factors in making decisions (Fussel 2007). Planned adaptation is expected to become more significant as it allows adaptation to meet changing circumstances and is more sustainable (Walker et al. 2013).

Adaptation strategies take many forms, e.g., technological, behavioral, financial. They are also context-specific and varying across locations among individuals, groups, and communities and over time (Smit and Wendel 2006). A community's ability to cope with and recover from the impact of recurrent climate hazards depends on the knowledge, skills and resources available. Moreover, to ensure that these hazards would not have longer-lasting adverse consequences, building resilience is crucial. Resilience emphasizes the ability of households or communities to absorb and recover from shocks while positively adapting and transforming structures and means for living in the face of long term-changes and uncertainty (OECD 2013).

Also worth noting is that perception influences adaptation decisions. For example, farmers' perceptions of changes in climate and their possible consequences influence both their farming and non-farming strategies to build resilience (Monirul Alam et al. 2017). Moreover, the underlying social and institutional processes that create capacity, motivations and objectives of adaptation actions are critical (Elrick-Barr et al. 2014). This points to the importance of social cohesion, inclusiveness and open participation in decision-making in a community, usually referred to as social capital. Activities that can enable people to build social capital for the collective good can reduce vulnerability (UNDP 2004).

The major determinants of social capital include group dynamics, networks, trust, and norms. Group dynamics involve participation in group activities and decision-making. Networks may be between members of the same community or different communities, or different groups. Trust involves solidarity and belief among the community members while norms guide the actions of the community. Networks and norms help in information dissemination, and raising awareness and preparedness, and making proactive adaptation decisions. Similarly, social capital has a significant role not only in sharing resources for recovery after a disaster but also in providing moral support (Sanyal 2017).

Institutional support, particularly at the local government level, is an enabling factor in improving the adaptive capacity of households and communities. One challenge is the linkage not only between the different tiers of government, i.e., from the national to local level as well as the private sector and community organizations. An important aspect is how actions at the household scale link to higher-level social organizations. Such analysis is intended to contribute to policy development for vulnerability reduction and enhance resilience (Elrick-Barr et al. 2014).

Methods

Design

The explanatory sequential mixed methods design was adopted in this study. The design occurs in two distinct interactive phases (Creswell and Clarke 2011), starting with collection and analysis of quantitative data followed by the collection and analysis of qualitative data to help explain and complement the initial quantitative results. Specifically, a survey of 100 household heads in each country was conducted to gather quantitative data while qualitative data were obtained through focus group discussions with participants representing agriculture and fisheries. When possible, FGDs were also conducted separately for male and female residents.

Selection of study areas

The selection of Battambang and Prey Veng in Cambodia and Bulacan and Pampanga in the Philippines (table 6.1) was based on reported losses and damages due to flooding and drought in the last ten or more years. Both were in areas prone to physical manifestations of climate variability or change such as droughts, floods, episodes of heavy rainfall, and long-term changes of mean values of climate variables (IPCC 2012). Kamchay Mear in Prey Veng province and Banan in Battambang province are the most vulnerable districts in these provinces. These are important areas for agriculture, particularly rice farming.

Table 6.1. Study areas and major climate hazards experienced

Country	Province/Region	District/Municipality	Major climate hazards experienced
Cambodia	Prey Veng province Battambang province	KamchayMear district Banan district	Flood, drought, windstorm
Philippines	Pampanga	Municipality of Guagua	Flood, typhoon, sea level rise, drought

In the Philippines, both municipalities of Guagua and Paombong are highly susceptible to flooding due to their low elevation (1 m above sea level) and agricultural livelihoods (e.g., farming, fishing, aquaculture). Flooding, stronger typhoons and rainfall variability have been reported to affect these productive activities (LCCAP Guagua, PDRRMC Bulacan).

For each country, rural communities in provinces or regions affected by climate-related hazards were chosen as study sites, in consultation with concerned bodies and local authorities. The selected communities are districts in Cambodia or municipalities in the case of the Philippines.

Survey respondents

The main intention of the survey was to provide a description of household and community-level adaptation practices without generalizing them for the whole municipality or district. About 100 respondents took part, representing each household in the study (see table 6.2). Samples of survey respondents were chosen primarily based on resource availability and accessibility of the target areas.

Table 6.2. Survey respondents by study site

Study site	No. of respondents
Cambodia	102
Prey Veng	53
Battambang	49
The Philippines	100
Guagua	50
Paombong	50

Data collection and analysis

Primary data were gathered through the household surveys and focus group discussions. Data on household socioeconomic profiles, types of climate hazards experienced and their impact on livelihoods, past and current adaptation strategies or adaptation decisions, adaptation plans, and determinants of adaptations were obtained from the survey. To better understand the climate-related hazards, their intensity, frequency, duration, and the size of the area affected were determined in order to assess their impacts over the years. Respondents were asked to record this information for at least the past ten years.

Focus group discussions were conducted to gather information on collective and community-based adaptation measures in the most vulnerable areas such as villages or communes of the municipality, township or district selected. Focus groups for various sectors (e.g., agriculture, fisheries), each consisting of eight to twelve participants, were held to differentiate their vulnerabilities and adaptation needs. Two focus groups were held in each target community. Separate discussions were held for male and female residents of Paombong and Guagua to capture gender perspectives on adaptation to climate-related hazards. The team was unable to conduct separate FGDs for male and female groups in Cambodia due to the unavailability and/or inadequate number of female participants.

Descriptive analytical tools such as frequency and percentage were employed to analyze quantitative data derived from the household survey while information obtained from the focus groups was subjected to thematic and content analyses. Responses were used to contextualize the experiences, practices, and lessons learned of rural households and communities in order to explain and analyze their adaptation measures that would contribute toward planning of climate response strategies and climate-resilient development. Comparative analysis of adaptation strategies across the country cases was done to draw lessons and possible policy recommendations.

Results

National policy and institutional setting

The Cambodian government formulated its National Adaptation Programme of Actions to Climate Change (NAPA) in 2006. Along with government bodies, development agencies have established their program interventions through enhancing knowledge and providing technical assistance in order for farmers to cope with the impact of climate change. Provincial, district, commune, and village-level authorities generally manage and control local development.

Two national policies in the Philippines have a major influence on climate response strategies at the local level. These are the Climate Change Act (CCA) of 2009 and the Disaster Risk Reduction and Management (DRRM) Act of 2010. The focus shifted from relief and recovery to risk prevention and mitigation and preparedness. Both policies placed the local government units (LGUs), namely the provinces, municipalities and barangays (villages) in the frontline of formulation, planning and implementation of climate change action plans.

Policies in both countries aim to enhance the role of local government in climate change actions and mainstream climate change in local development planning. In Cambodia, the entry points are sub-national planning and financial systems. In the Philippines, the entry points are the Comprehensive Land Use Plan and the Comprehensive Development Plan of each municipality. Planning is an indication of proactive or anticipatory adaptation strategy. Reactive measures such as seed distribution for farmers to re-plant damaged fields and recover from losses is a continuing practice. Breakthroughs include awareness raising on climate change and an early warning system at the local level to support proactive adaptation options.

Demographic profiles

The population of the study areas in Cambodia is growing annually at the rate of 1.25 percent to 1.59 percent. Poverty incidence has gone down between 2006 and 2012 in both Kamchay Mear (from 33.1 percent to 22.8 percent) and Banan (from 37.3 percent to 26.6 percent).

In the Philippines, Paombong has a population growing at a faster rate (2.18 percent) than the national (1.9 percent) and regional (2.1 percent) growth rates. Paombong also has a higher poverty incidence (10.4) than Guagua's (3.8). Poverty incidence in Paombong has also been rising over the years (table 6.3).

Table 6.3. Population trends and poverty incidence in the study sites in Cambodia and Philippines

Study area	Population annual growth rate		Population density		Poverty incidence	
	Year	%	Year	(persons/km^2)	Year	%
Cambodia						
Kamchay Mear	2005–10	1.59	2005	192	2006	33.1
					2012	22.8
Banan	2005–10	1.25	2005	89[a]	2006	37.3
					2012	26.6
Philippines						
Paombong, Bulacan	2000–10	2.18	2000	886	2006	7.6
			2015	1,271	2012	10.4
Guagua, Pampanga	2000–10	1.31	2000	1,567	2006	4.1
			2015	1,904	2012	3.8

Notes: [a] Data for Battambang province; In the Philippines, as of 2010, national annual growth rate was 1.9%; and Region 3 growth rate was 2.1%.

Sources: Cambodia: NCDD Commune data (http://db.ncdd.gov.kh/cdbonline/home/index.castle); ADB 2014; Ministry of Planning, July 2012, Poverty Reduction by Capital, Provinces, Municipalities, Districts, Khans and Communes, Sangkats; Commune Data Base (CDB), 2004–2012.

The Philippines: Census of Population and Housing, Local Government Units of Guagua and Paombong, and Provincial Plans of Bulacan and Pampanga; NSCB/World Bank/AusAid Project on the Generation of the 2006 and 2009 City and Municipal Poverty Estimates, Bulacan Provincial Physical Framework Plan; and Pampanga Provincial Physical Framework Plan.

The changing climate has implications for the socioeconomic development of the locality, as indicated for example by population growth, poverty incidence, and land use. Poor households depend on natural resources such as land for livelihood, as observed in both Cambodia and the Philippines. In both Cambodia and the Philippines population growth and poverty may exert pressure on resources such as intensified use of land for various uses, hence increasing vulnerability to climate variability. This stresses the importance of taking into account the socioeconomic context in climate change adaptation and development planning.

Climate hazards: Past and future

In Cambodia, Banan district of Battambang province has been experiencing more droughts than floods. Battambang experienced drought nine times between 2002 and 2016, while Prey Veng province suffered from drought six times between 2004 and 2016. In both study sites, floods happened about 12 times between 1996 and 2016. Meanwhile, both droughts and flooding occurred more frequently, almost yearly, after 2000. Climate projections indicate that changes in rainfall and temperature could aggravate agricultural productivity losses (UNDP Cambodia 2010; Yi 2012).

In the Philippines, both Paombong and Guagua are highly susceptible to flooding. The source of flooding is a mix of typhoons, rainfall and other natural and physical factors. Sea level rise is a contributory factor to prolonged tidal flooding (from Manila Bay). The Bulacan Provincial Development Plan cited an estimate of 7 mm annual sea level rise experienced by towns facing Manila Bay (Kahana et al. 2016). As reported in the Paombong Contingency Plan, the elevation ranges from only 0.5 m to about 6 m above sea level. Meanwhile, Guagua is only about 1.2 m above mean sea level, according to its DRRM Plan. Guagua's low elevation and an annual subsidence rate of 3 cm makes it vulnerable to flooding. Downscaled climate change projections by the national meteorological agency for Bulacan and Pampanga revealed that summers will become hotter, and dry seasons longer; wet seasons will become more wet, and rainfall more intense.

Household-level analysis

This section shows the results of the household surveys in Cambodia and the Philippines.

Cambodia

In Cambodia, more than half of the respondents (60 percent) were women with an average age of 46 years (table 6.4). The youngest was 21 years while the oldest was 79 years old. More than half of them (52 percent) had completed primary school, the same number finished secondary school (21 percent) and senior high school (21 percent), and one had a college degree. They were residents of the area for an average of 34 years, the oldest resident having lived in the area for 75 years.

Table 6.4. Socioeconomic profile of respondents, Cambodia

Characteristic	N	%
Sex		
Male	40	40
Female	61	60
Age		
Average	46	
Min	21	
Max	79	
Educational attainment (n=96)		
Primary school	50	52
Secondary school	20	21
High school	20	21
Undergraduate	1	1
Graduate	1	1
Vocational	4	4
No. of years residing in the village	Average = 33.81, Min = 3, Max = 75	
Total no. of household members	Average = 5.17, Min = 1, Max = 12	
No. of members who are working	Average = 3.4, Min = 1, Max = 9	

About three or four members per household were reported as being largely dependent on non-farm sources for their livelihood (table 6.5). On average, an annual income of US$3,257 was reported from various agricultural and non-agricultural sources. For a household of five, this annual income is higher than the average consumption (US$1,703.40), but still lower than the US$2.00 per person per day poverty line in Cambodia (equivalent to US$3,650) (ADB 2014). Agricultural income included growing crops, mostly rice, livestock or poultry farming, waged farm labor, and fishing. Non-agricultural sources such as pensions, remittances, non-farm waged labor, and self-employment were also reported. For Prey Veng, average farm and non-farm incomes are US$492 and US$1,274, respectively, while for Battambang, these are estimated to be US$1,437 and US$3,311, respectively. The largest source of farm income came from crop production, while waged labor contributed the most to non-farm income sources. The relatively high income reported in the study areas is an indication of reduced poverty incidence.

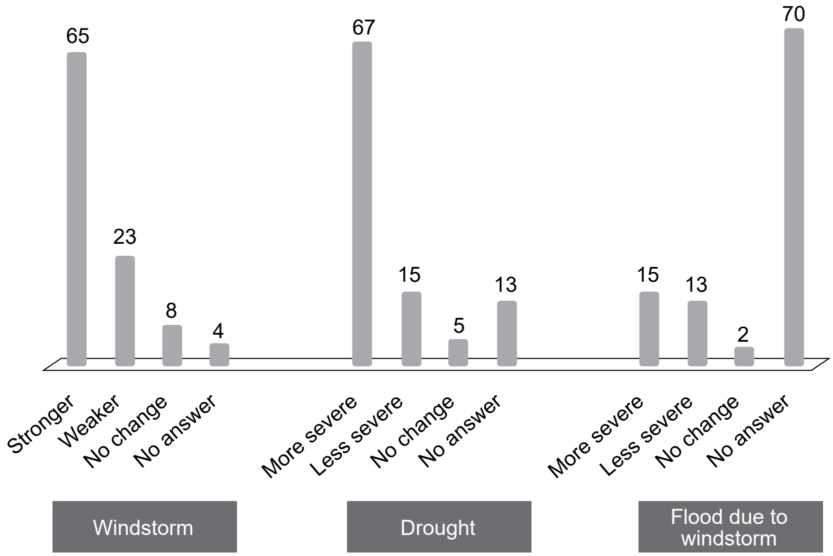
Table 6.5. Income from farm and non-farm sources, Cambodia

Study site	Farm income	Non-farm income	Total
• Prey Veng	492	1,274	1,766
• Battambang	1,437	3,311	4,748

Cambodia commonly experienced climate-related hazards such as floods and droughts or dry spells and is also uniquely affected by windstorms. Since at least the past ten years, the common climate-related hazards affecting the Cambodia study sites were windstorms and droughts. Dry spells were occurring more frequently, lengthening, and affecting increasingly larger areas. There were also few cases of reported flooding due to windstorms (fig. 6.2). Drought is the major climate-related hazard experienced across the study areas. A majority (67 percent) of respondents perceived that droughts were becoming more severe, while 15 percent observed that they were becoming less severe.

Windstorms were another key climate-related hazard that affected the study areas. The majority of farmers (65 percent) assessed that windstorms had become stronger, with some (23 percent) indicating that they thought

Figure 6.2. Perceived intensity of common climate-related hazards, Cambodia (% responding)



the opposite was true. Flooding due to windstorms was also felt in several areas; flood intensity was rated as more severe by some (15 percent) and less severe by almost the same number (13 percent) of respondents. The majority (70 percent) did not experience floods due to windstorms. Overall, damage caused by flooding due to various reasons in Cambodia has been less severe, occurred less frequently, with not much change in duration and affected area over the years included in this study.

Drought in Cambodia has resulted in poorer crop quality and decreased productivity in rice, livestock, cash crops and vegetables. Drought-related damage has been observed to be more severe than those caused by windstorms and floods in the areas studied. Moreover, threats due to windstorms and floods have increasingly been felt starting 2008. To cope, local people temporarily relocate from their homes to safer areas such as pagodas, schools, and national roads until floodwaters come down (table 6.6). To recover from agricultural losses, people replace damaged crops through transplanting or seed broadcasting. Most families also are increasing their home gardens as a source of extra income. Given very limited livelihood options, some families whose crops were totally damaged by floods and had less land to till migrated to other provinces in Cambodia or to neighboring countries such as Vietnam and Thailand to seek paid work.

Table 6.6. Common household adaptation strategies to climate-related hazards, Cambodia

Climate-related hazard	Adaptation strategy
Windstorm/flood	• Relocating to safe place • Replanting to replace damaged crops • Home gardening • Migration
Drought	• Digging wells and canals • Switching to short-duration rice variety • Increasing use of chemical inputs • Borrowing money • Migration

To address drought, inhabitants of the Cambodia study sites would dig wells and canals in order to make water available for agriculture, including paddies and home market gardens. Since about 2010, some have shifted to short-duration rice varieties. This practice has also allowed rice farmers to double or triple crop. Unfortunately, many have generally increased their use of chemical fertilizers to help maintain rice yields. Borrowing from local merchants or microcredit institutions was another adaptation strategy used by local farmers.

Implementing a particular adaptation option was based on a number of considerations. Farmer respondents were asked to identify the determinants of their adaptation decisions based on the effectiveness of the practice to reduce damage, cost of adopting the strategy, knowledge or skills about the strategy, assured availability of access to technology in implementing the strategy, and belief in the early warning information. About 39 percent of farmers in the Cambodia study considered early warning information as a key consideration in choosing an adaptation measure, while 20 percent chose a strategy that they considered effective.

We also examined how rural households plan for future climate-related events. Most of the respondents in Cambodia expressed an intention to continue implementing their present adaptation practices. Specifically, 91 percent would keep with their current strategies to adapt to hazards due to windstorms and only 9 percent to adopt new practices. Climate-smart agricultural practices and technologies help improve land and water management that could build resilience of farming systems, improve agricultural productivity, and protect the environment (Nang 2013). To address flood and drought hazards, 100 percent and 74 percent, respectively indicated their intention to retain current practices.

The study also explored the collective or community-level adaptation strategies in the study areas. A large majority (90 percent) of responding farmers from Cambodia indicated that they did not have any community-level measures to adapt to climate-related hazards, indicating low social capital. Among the major reasons cited were: not knowing how to act collectively to deal with threats and hazards; a lack of community interest in working with others; or not knowing enough people in the area.

The Philippines

Males (79 percent) dominated the respondents from the Philippines (table 6.7). They were older, with a mean age of 58 years, the youngest being 28 and the oldest 82; some 28 percent had completed secondary and 23 percent had completed primary education. Nine respondents completed college degrees. All were residents of the area for longer period of about 51 years.

An average household size of five was common in the Philippine study sites with about one to two family members who are working. Most households in Paombong were largely dependent on non-farm sources for their livelihood, while large dependence on farm income sources was reported for the case of Guagua (table 6.8). Agricultural sources included crop production, mostly rice, livestock or poultry farming, farm-waged labor, and fishing. Non-agricultural sources such as pensions, overseas remittances, non-farm waged labor, and self-employment activities were also reported. Respondents estimated an average annual income of US$3,222 from various agricultural and non-agricultural sources.

Table 6.7. Socioeconomic profile of respondents, the Philippines

Characteristic	N	%
Sex		
Male	79	79
Female	21	21
Age		
Average	58	
Min	28	
Max	82	
Educational attainment (n=100)		
Primary school	19	19
Secondary school	23	23
High school	8	8
Undergraduate	28	28
Graduate	4	4
Vocational	9	9
No. of years residing in the village	Average = 51, Min = 6, Max = 82	
Total no. of household members	Average = 5.09, Min = 2, Max = 14	
No. of members who are working	Average = 1.80, Min = 0, Max = 6	

Table 6.8. Income from farm and non-farm sources, the Philippines

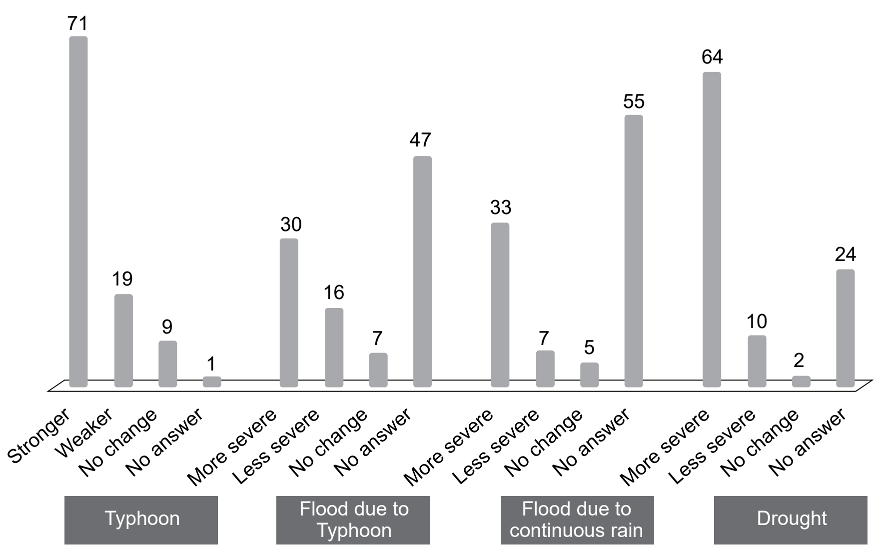
Study site	Farm income	Non-farm income	Total
Guagua	1937	1214	3151
Paombong	881	2413	3294

Reported average farm and non-farm incomes in Philippine study sites respectively are US$3,290 and US$4,960 for Guagua while these are estimated to be US$2,500 and US$8,948, respectively for Paombong. These income levels are close to the poverty threshold level in the region (PSA 2012). The relatively higher average income is accounted for by the sample fishing households who earned more. Crop production was the biggest contributor to farm income sources while waged labor contributed the most to non-farm income sources.

The Philippines has been badly affected by floods due to typhoons and continuous rains of increasing severity, affecting large parts of the study sites (PSA 2012, 2013). In particular, respondents from Paombong reported longer floods as compared with Guagua, due Paombong's lower elevation. Many recalled Typhoon Ondoy (Ketsana) which struck central Luzon in 2009 where the Philippine study sites are located. Ondoy, accompanied by heavy rain and strong winds, caused flooding which lasted for more than a month in some areas in Bulacan.

The majority (71 percent) of rural households in the Philippine study sites perceived that typhoons had become stronger than before, occurring more frequently and for longer periods, with wider coverage (fig. 6.3). Those with personal knowledge of flooding due to typhoons (30 percent) assessed that this threat was becoming more severe. About the same number (33 percent) rated that damage caused by flooding due to continuous rain was likewise increasingly severe. Fewer (16 percent and 7 percent, respectively) perceived that threats brought by these events had become less severe.

Figure 6.3. Perceived intensity of common climate-related hazards, the Philippines (% responding)



Several droughts were also reported and their impacts were observed by the majority (64 percent) to have become more severe. Some (24 percent) indicated they were not directly affected by drought. Impacts of droughts were felt by more respondents in areas whose main livelihood was farming rather than those engaged in fishing or aquaculture. Predominantly rice-farming areas considered typhoons and droughts as most destructive whereas those whose main livelihood was fish farming reported greater vulnerability to flood and typhoons.

In particular, typhoons caused more severe damage to crops in Guagua where the majority reported up to 60 percent damage to crops due to typhoons. A large proportion had suffered total loss of their crops around harvest time; Paombong reported that 82 ha of rice were damaged due to Typhoon Ondoy. Of the more recent events, Ondoy ranked second as the most destructive in terms of affected area, next to typhoons Pedring and Quiel in 2011, which affected more than 96 ha and caused total damages of more than PhP1.7 million (US$36,900). In Guagua, Ondoy ranked first as the most devastating, affecting about 1,900 ha with total damages of up to PhP121million (US$2.5 million), affecting rice and vegetable crops as well as freshwater and brackish water fishing. Typhoons also damaged livestock and aquaculture. As related by one of the FGD participants:

> Aside from damage caused by flooding to crops, those who were into livestock production also reported livestock deaths and sickness causing income losses and additional expenses. Meanwhile, fish kill and overflowing fishponds were a common scenario causing inability for many to recover their capital. Fish kill actually happened with both typhoons because of flooding or drought due to a lack of oxygen.

FGD participants from Paombong added that flooding may have also been caused by the release of water from Angat Dam due to heavy rainfall. Higher tides had also caused saline water intrusions in their area making the land unsuitable for growing crops. This has led to the conversion of most farm land to fishponds.

These climate change-related events have also caused a variety of social impacts such as threats to public safety due to severe flooding and rains accompanied by strong winds, illnesses due to changing weather patterns and vector-borne diseases, and anxiety or depression due to economic losses. Children's school attendance also suffered due to suspension of classes. Power interruptions, loss of telecommunications signals and transport disruptions were also experienced in some areas which affected relief efforts and response particularly to remote coastal areas.

Rice farmers in the Philippine study have found that draining their paddies by cutting a groove in the surrounding dike or embankment to channel the excess water out (table 6.9) or clearing clogs from irrigation canals is an effective way of protecting farm land. Some farmers also placed sandbags along the embankments to prevent water from rushing into their fields. These are traditional flood control techniques learned from elders and are still being practised.

Table 6.9. Common household adaptation strategies to climate-related hazards, the Philippines

Climate-related hazard	Adaptation strategy
Rice farmers	
Typhoon/flood	• Draining the paddy • Clearing the canals • Sandbagging • Avoiding fertilizer application • Early harvesting • Closing check gates • Adjusting cropping calendar • Converting to fishponds
Drought	• Planting alternative crops • Using water pump (provided by LGU)
Fisherfolk	
Typhoon/flood/continuous rain	• Using fishnets • Early harvesting • Raising embankment elevation • Sandbagging

To avoid further damage to soil quality, farmers avoid applying fertilizer prior to the onset of continuous rains. Another beneficial strategy was to harvest the crops earlier to prevent damage. A few mentioned adjusting the cropping calendar. When drought struck, some rice farmers planted alternative crops such as *mongo* (mung beans) and peanuts. They reported that the Municipal Agricultural Office assisted by providing communal water pumps, diesel fuel, and seeds.

Fisherfolk used nets to cover ponds, which was considered the most effective strategy to prevent fish from being washed out when water overflows due to heavy and continuous rains. Whenever possible, early fish harvesting was likewise employed primarily to recover input costs. A few would hire extra workers to help raise the level of embankments to reduce the chance of loss of water and fish during the flood season. Livestock farmers secured their animals inside cages or other shelters during typhoons or heavy rains.

In separate focus groups in the Philippine case studies, mothers related that they play important roles before, during and after natural calamities such as a typhoon or flood. These included training their children how to be prepared and instructing them what to do during and before the event, taking stock of food, water and other necessities, and helping male family members in strengthening house structures or doing repairs. Some women also provided labor support for early harvesting or cleaning farms and fishponds. FGD participants from a women's group in Paombong mentioned that "some mothers volunteered to help clean the canals and monitor the check gates and this practice has been found to be helpful and effective." At the community level, a church-based women's group in cooperation with a youth organization in Paombong were involved in packing and distributing relief goods. Women village leaders together with local government units were also active in disaster response.

Farmers were asked to identify the determinants of their adaptation decisions based on the effectiveness of the practice to reduce damage, cost of adopting the strategy, knowledge or skills related to the strategy, assured availability of access to technology in implementing the strategy, and trust in the early warning information.

In the Philippine study sites, the credibility of early warning information came out as top choice that determined adaptation decision among 28 percent of farmer respondents. Farmers also considered knowledge or skill (22 percent) and assured availability of or access to technology in implementing the strategy (22 percent) as major determinants when implementing a particular strategy. Credibility of early warning information also ranked as primary determining factor among 46 percent of fisherfolk. Another top choice among those practicing aquaculture was knowledge or skill in implementing a strategy (25 percent).

The adaptation plans of Philippine households in our study were focused on protecting both households and livelihoods. About half of the strategies pertained to maintaining existing practices they identified to safeguard their sources of livelihood. The rest of their responses referred to safety measures to protect their families and properties. These included having adequate stocks of food and water, strengthening and securing their houses, relocating to safe place, or simply staying inside their houses.

Most respondents (58 percent) from the Philippine study areas also articulated the absence of collective action, implying a low level of social capital. They explained that many families were primarily individualistic and would rather work for the needs of their own households, many were not concerned or were not interested in helping others, or that the traditional spirit of volunteerism (*bayanihan*) no longer existed. The presence of a farmer's association in Guagua, on the other hand, was instrumental in facilitating community-based adaptation measures such as mutual help for early harvesting and hauling, cleaning and repair of irrigation canals, and closing the check gates.

Conclusion

Both Cambodia and the Philippines have experienced an increase in climate-related hazards such as floods and droughts, extended dry spells and intensive storms. There was a general observation across the two countries that these events have become more intense, droughts have brought more losses to agricultural productivity, typhoons accompanied by strong winds have become longer in duration, and rainfall patterns more intense and erratic. Across the study sites in both countries, a common anecdotal observation was that temperatures had risen in recent years. The changing climate in the more recent years such as flooding and drought brought economic losses due to crop damage, low productivity, and fish kills.

Even under unfavorable climatic conditions, a number of adaptation measures in the Philippines cases were estimated to have reduced damages and losses of up to 100 percent. Rural households adopted strategies that could be classified as either reactive or proactive. Household adaptation measures implemented in the study locations were largely reactive in nature and only implemented immediately prior to, during or soon after an extreme climate event. In both country case studies, the effectiveness of a strategy, knowledge and ability to use it, and the ease of implementation were among the common reasons given for continuous implementation of current adaptation practices. Unfortunately, there was seemingly the same low level of attention paid by both local communities and relevant authorities in anticipation of these events, despite the observed increased intensity and frequency, longer duration, and wider coverage area of such climate events. While there had been expression of adaptation plans, these were mainly focused on short-term measures aimed at protecting households and livelihoods just prior to and during a climate event in the Philippine cases.

In Cambodia, the majority expressed the continuation of current adaptation practices. This was also a common observation in an earlier study, which revealed that despite repeated occurrences of climate-related events, the responses of households, communities and local government units focused on short-term rather than long-term measures to manage risk and prevent damage (Francisco et al. 2011). Experts have recommended that adaptation to climate change move beyond the merely reactive (Someshwar n.d.).

Ensuring effective and meaningful proactive adaptation strategies requires community-level participation and a strong enabling environment to facilitate collective action. This issue of participation needs to be addressed to enhance community-level adaptation measures. Government and other external intervention appear to be a critical factor to encourage local people's collective action through recognized organized local groups. With the largely individualistic nature of rural households, the role of other sectors such as farmers' organizations and church-based groups provided opportunities for social capital in action. For example, Caritas Cambodia, a Catholic church-based organization, was instrumental in relocation activities. These organizations had been found effective seemingly because of the high level of community trust in them, having been in existence for some time.

Several studies (e.g. Sanyal 2017) show linkages between social capital and the different phases of disaster management. In particular, disaster preparedness and response phases have been seen to have some linkages with social capital. Community networks help improve the readiness of the local populace for impending disasters. Networks and norms are also useful for information gathering, dissemination and early warnings. Group dynamics, norms, mutual trust and networks all seemed to work together during emergency evacuation, as seen in the case of Caritas Cambodia.

Social capital indeed plays a critical role during environmental shocks such as those posed by climate change (Chamlee-Wright 2010; Dynes 2006; Prasad et al. 2014 as cited by Aldrich et al. 2016). Individuals with strong social ties to neighbors are more likely to regain stability. Research has shown that before the onset of environmental challenges, families and close social networks devise coping strategies in preparation and these homophilous networks facilitate physical, emotional and financial support during an extreme event (Hurlbert et al. 2000 as cited by Aldrich et al. 2016).

Recent experience with community-level adaptation in the Pacific highlighted that people-centered strategies are more cost-effective for reducing climate-related risks (UNISDR 2012). Strengthening institutions at local government level and the sharing of information and experiences through local-level networks (i.e., district, village, barangay) contribute to the scaling-up of local initiatives.

To sum up our recommendations, rural households need to view risks in a longer-term perspective, and adopt more proactive ways of managing the risks to their livelihoods of extreme weather events. Importantly, proactive adaptation strategies require community-level participation and a strong enabling environment to facilitate collective action. Government intervention to encourage collective action at the local level through recognized and organized groups will play a critical role in this process. Enhancing indigenous knowledge systems may also be important since farmers draw largely on local knowledge and personal experience to determine signals from the environment and consequently, make better decisions. It is also important to reassess adaptation strategies over time in terms of availability, benefits, costs and effectiveness for planning and decision-making. Thus, the accessibility of key information is critical to the implementation of climate change-related adaptation strategies.

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7

The benefits of using rice straw-derived solid fuel to reduce open burning emissions in the Mekong Region

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The Mekong Region hosts two of the world's top five rice exporters, Thailand and Vietnam (Trade Map 2016). With the shift to multiple cropping each year, farmers need to quickly clear their paddy land of surface residues, comprising mainly of rice straw (RS), after each harvest in order to plant the next crop. Most farmers in the region have preferred to clear the land by burning the rice straw left in the field after each harvest, a practice that is termed field burning or open burning. An estimated 60 million tonnes of rice straw was generated in 2015 in the five Mekong Region countries and, on average, about 50 percent of this was subjected to open burning (Kim Oanh et al. 2018). RS open burning releases large quantities of toxic air pollutants and greenhouse gases (GHGs). A number of short-lived climate forcing pollutants (SLCPs), e.g. black carbon (BC), are also emitted. Thus, the emissions affect not only local air quality but also regional/global climates (Kim Oanh et al. 2011; UNEP and WMO 2011).

The rice farmers, however, have little knowledge about the negative implications of emissions from RS open burning (Kim Oanh et al. 2013). Yet there are several non-open burning alternatives, depending on economic conditions and agricultural practices, e.g., using RS as a medium for mushroom cultivation, animal feed and bedding, or as compost. Each has its drawbacks. For example, the presence of a high silica (Si) content in RS impedes digestion if it is used directly as livestock feed. In addition, the collection and transport of bulky RS for off-site use requires extra labor and transportation costs.

Loose RS has been used as cooking fuel in simple tripod cookstove/s (CS) traditionally in rural areas; however, this is an inefficient cooking system that consumes great amounts of fuel when compared to others (i.e. wood fuel burned in improved cookstoves). Moreover, the high emissions of air pollutants generated through incomplete combustion affects air quality in confined indoor spaces, thereby increasing the health risks of exposure to toxic air pollution indoors.

However, more efficient RS-derived solid fuels can be produced by densification and include, for example, roped/bundled briquettes and pellets that are easier to store or transport than loose RS. However, these conversion technologies have not been fully developed or adapted for RS. Additionally, using RS-derived solid fuels for cooking remains a challenge due to technical issues in the production of suitable products as well as farmers' limited awareness about the adverse effects of open burning. Thus, while the use of RS pellets for cooking is promising, there are obstacles to overcome, both in the pellet production and gaining user acceptance of the RS pellet-CS systems.

Therefore, the successful development of suitable densified fuels from RS for cooking is an opportunity to demonstrate the feasibility of this technology and to encourage farmers not to burn RS in the field. This can result in multiple benefits, e.g. reducing demand for wood and fossil fuels and at the same time eliminating the emissions from open burning. This chapter presents an assessment of the potential co-benefits of turning RS into cooking fuels to minimize open burning practices in Thailand, Vietnam and Cambodia. The assessment is based on information gathered from primary surveys conducted in selected agricultural areas in the target countries to investigate current RS generation and utilization, along with the emission-testing results of developed fuel-CS systems.

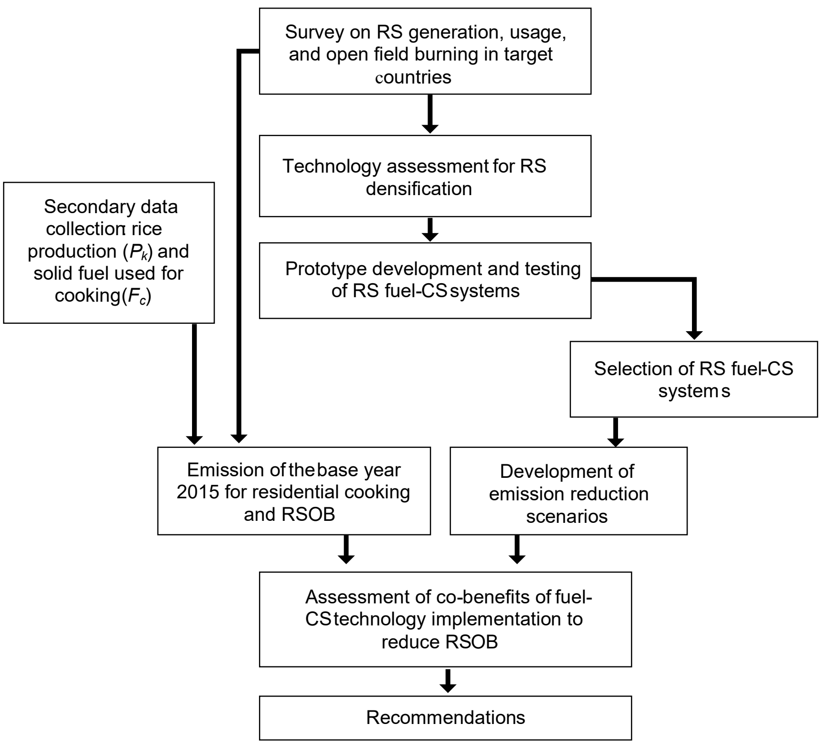
The development of the RS solid fuels and the emissions testing for the developed fuel-CS systems were all conducted at the Asian Institute of Technology (AIT) in Thailand. The activities were carried out under the Sustainable Mekong Research Network (SUMERNET) Phase 3 research project "Turning rice straw into cooking fuel for air quality and climate co-benefit in selected Greater Mekong Subregion (GMS) countries (RS co-benefit)." Induced changes in the emissions of toxic air pollutants and

GHGs due to the elimination of open burning and the simultaneous use of RS-derived solid fuels to replace solid fuels in cooking were quantified under two scenarios involving different fuel-CS systems. The benefits to air quality of each scenario were quantified according to their effects on reducing emissions of toxic air pollutants. Each scenario's potential for climate forcing mitigation was quantified using the Global Warming Potential (GWP) metric in CO_2 eq (20 year-horizon), accounting for both GHGs and SLCPs. The results will provide policymakers with supporting evidence to initiate and facilitate the enforcement of non-burning alternative RS management that can be replicated throughout the Mekong Region and beyond.

Methods

Research framework

Figure 7.1. Study research framework



The overall research framework is presented in fig. 7.1. A survey of current RS generation and utilization was undertaken in selected agricultural areas in Thailand, Vietnam and Cambodia. RS samples were collected during the surveys and analyzed in the laboratory for moisture and dry biomass content. The survey generated information on the fraction of residue-to-production ratio (S_k), fraction of RS subjected to open burning (B_k) and the harvesting methods that were essential in the calculation of the amount of RS biomass subjected to open burning and associated emissions. Available RS-derived solid fuel densification technologies were reviewed and assessed in controlled experiments at AIT. RS-derived solid fuels were characterized for their fuel properties and test burned in selected fuel-CS systems using an experimental hood system available at AIT. This system has been described in detail in our previous studies (Kim Oanh et al. 1999; Kim Oanh et al. 2005).

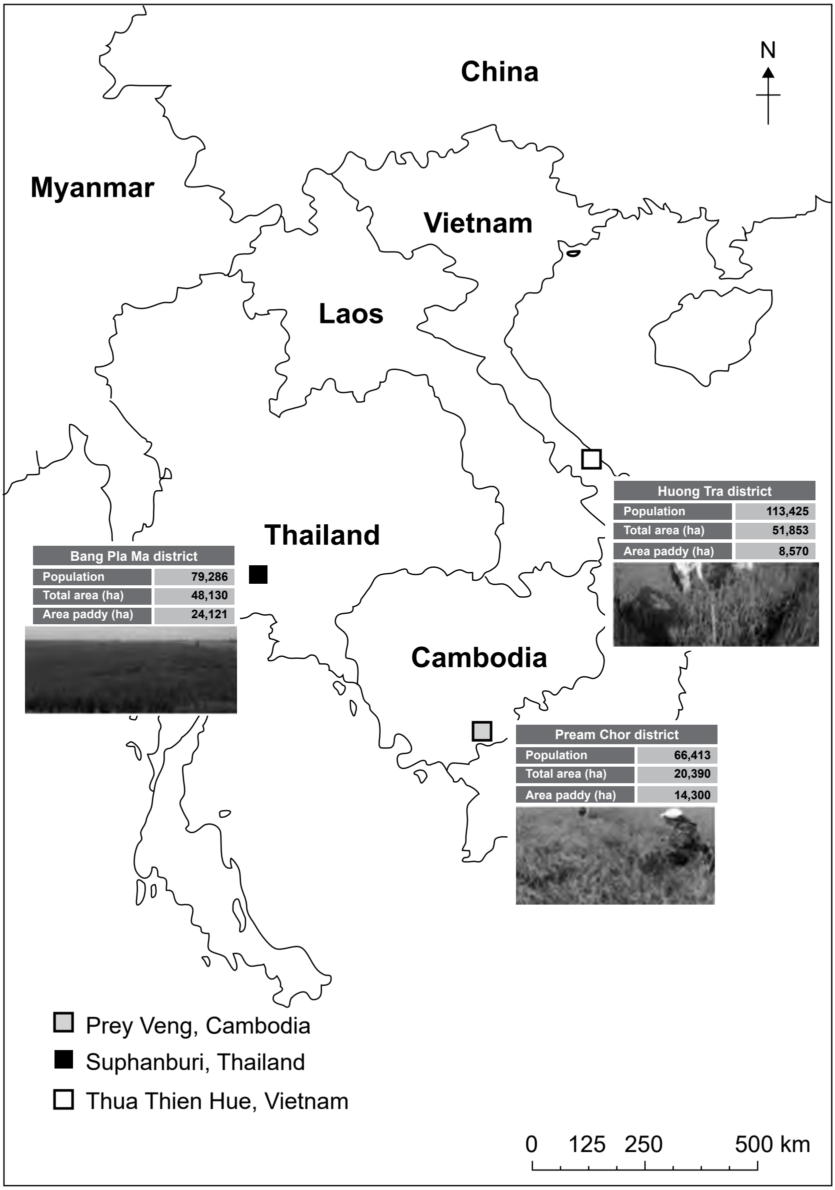
Secondary data on the consumption of solid fuels for residential cooking in Thailand, Vietnam and Cambodia were obtained from the respective national statistics. This information was used to analyze the volume of solid fuels that could potentially be replaced by RS-derived solid fuels for cooking in the three countries. Further, emission scenarios were developed that incorporated the results of RS-derived solid fuel-CS emission testing. Finally, an assessment of the co-benefits of implementing the RS-derived solid fuel-CS technology was undertaken using the changes in the emissions induced by the scenarios as compared to the base year emissions of 2015.

Survey

A survey of selected rice growing areas in Thailand, Vietnam, and Cambodia (fig. 7.2) was conducted to obtain representative information on RS open burning practices.

In Cambodia, the Pream Chor district was selected out of 13 districts in Prey Veng province, known as the largest rice-producing province in the country. Pream Chor district has a total area of 20,390 ha with a population of 66,413. In Vietnam, Huong Tra district, with an area of 8,570 ha and a population of 113,425, was selected from the nine districts/towns of Thua Thien-Hue province. The survey focused on the coastal commune of Huong Phong. In Thailand, the survey was undertaken in Bang Pla Ma district, Suphanburi province, central Thailand, which is also known as a rice-farming area. Bang Pla Ma has a total area of 48,130 ha with a population of 79,290.

Figure 7.2. Survey locations in Cambodia, Thailand and Vietnam



The surveys were conducted from April to September 2015 (in Thailand), May 2015, and August to September 2015 (Vietnam), and March to April 2015 (Cambodia) coinciding with the rice harvesting periods. A total of 290, 200, and 252 households (HHs) were surveyed in Bang Pla Ma (Thailand), Huong Tra (Vietnam), and Pream Chor (Cambodia), respectively. The surveys gathered information on the current utilization of RS and the fraction of RS subjected to open burning in the study areas. The project team in each country undertook the quantification of the RS biomass in the surveyed paddy fields. RS samples were collected from the fields (freshly after harvest) for moisture content determination, residue-to-production ratio, and yield (kg/ha) and used to estimate the total amount of RS dry biomass generated. The total above-ground biomass (available for RS open burning) and cut residue of RS (collectible for off-site use) were determined to represent the conditions of both manual and mechanical harvesting methods.

Development of RS-derived fuels

Three densification methods suitable for RS were investigated, namely, roping (making RS bundles), briquetting, and pelletizing. The three approaches were selected for assessment based on the following factors: feasibility, availability of necessary equipment to produce the solid fuel in the market, densification factor, and suitability for burning in available CS. The RS used in these studies were collected from a paddy in Bang Pla Ma, Suphanburi province, four days after being mechanically harvested. The collected RS was characterized using the proximate and ultimate analysis as detailed in several studies (Mai 2015; Rahaman 2015; Yin 2011). The prepared RS-derived solid fuels and the equipment used to produce the fuels are presented in fig. 7.3.

a) RS bundles

RS bundles (roped RS) were made in a range of sizes with a density two to three times higher than loose RS (Mai 2015). Both manual and machine-roped RS (using a roping machine) were produced. Bulk density measurement and proximate analysis were undertaken to characterize the roped RS.

Figure 7.3. Rice straw-derived fuel: Equipment and products

a. Handmade rope Roping machine and rope

b. Cold densification system and briquettes c. Pelletizing machine and pellets

b) RS briquettes (cold densification)

A small-scale cold densification system was developed at AIT that was able to densify RS biomass with and without pre-treatment. The system allows variation of the operational parameters such as the outer diameter, ratio of the inner hole to outer diameter, moisture content, applied pressure (maximum 79.06 MPa), binder ratio, and briquette height (Rahaman 2015).

c) RS pellets

A pelletizing system was developed to produce RS pellets. Rice straw in particular has a low pelletizing ability (i.e. it is difficult to convert into pellets) hence resulting in low mechanical strength of the pellets produced and at the same time the production process consumes a significant amount of energy. Sawdust, as a binder, was used in combination with chopped RS for improving pellet quality: the lignins in the sawdust provide additional mechanical strength. The physical and thermal properties of the prepared RS pellets were determined in the AIT laboratory using the methodology presented in Cuong (2016).

RS-derived fuels-cookstove system testing

The RS-derived solid fuels of manually (handmade) and machine-roped RS, and RS pellets were evaluated in selected fuel-cookstove (CS) systems and these were compared to the traditional method of burning loose RS in a simple tripod CS. Four fuel-CS systems evaluated for thermal efficiency and emissions: loose RS and tripod; handmade roped RS and Thai biomass CS (BCS); handmade roped RS and Thai improved BCS (IBCS); and machine-roped RS and IBCS. The thermal efficiency of these fuel-CS systems was determined using the conventional water boiling test (Kipruto 2011).

The RS briquettes were too big, so could not effectively be burned in any CS available at AIT, hence were not included in the emission testing study. Pellets, being small in size and of high density, could not be burned directly in simple or improved tripod cookstoves. A forced up-draft gasifier CS (GCS) was selected and was proven to successfully burn the pellets. However, due to time constraints, efficiency and emission testing was not conducted for this RS pellet-GCS system. Instead, secondary data from published literature on the thermal efficiency and emissions of the system were used in the analysis. Thus, the final data analysis included all five systems, four of which were tested during this project.

A hood was used for the emission monitoring to produce emission factors (EFs), expressed as the amount of a pollutant produced per kilogram of dry fuel burned in a selected CS system. The concentrations of carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), benzene, toluene, ethylene, and xylenes (BTEX) and particulate matter (PM) were measured from the hood chimney. The amount of fuel burned and the stack gas flowrates were measured to calculate EFs of each considered emission species.

The PM sampling was done using a cascade impactor with eight stages (i.e. eight size ranges of particles) while CO, CO_2 and CH_4 were measured with online gas analyzers (Rosemount Analytical's NGA 2000 MLT). The BTEX samples were collected using charcoal adsorption tubes and were analyzed in the laboratory using gas chromatography. BTEX sampling techniques and analysis were based on Method 1501 of the National Institute for Occupation Safety and Health (NIOSH 2003).

Emission calculation and co-benefit assessment

The emission inventory (EI) tool was used and the EI species included toxic pollutants of PM_{10} (PM with aerodynamic diameter equal or less than 10 μm) and $PM_{2.5}$ (PM with aerodynamic diameter equal or less than 2.5 μm), carbonaceous components of PM including BC and organic carbon (OC), gaseous pollutants of CO, non-methane volatile organic compounds (NMVOC), sulfur dioxides (SO_2) and nitrogen oxides (NO_x) and GHGs (CO_2, N_2O and CH_4).

The emission for residential cooking activity was estimated using Equation 7.1 below.

$$\mathrm{Em}_{\mathrm{i,j,k}} = \sum \mathrm{Fc}_{j,k} \times \mathrm{EF}_{i,j,k}$$

Where,

$\mathrm{Em}_{i,j,k}$ = Emission of pollutant *i* from fuel type *j*, burned in CS type *k*
Fc_{j} = Consumption of fuel type *j* (kg/yr) burned in CS type *k*
$\mathrm{EF}_{i,j,k}$ = Emission factor of pollutant *i* from fuel type *j*, burned in CS type *k*

The types of fuels and CS used in cooking in the three countries as of 2015 were obtained from the surveys and published records. EFs of various RS fuels–CS systems were mainly taken from the laboratory measurements of this project while for other types of fuels, the relevant secondary values from literature were used. The activity data, i.e. the fuel consumption data for residential cooking for 2015 in three countries, was obtained from the United Nations Statistics Division Energy Statistics Database (UNSDESD 2016) and relevant national databases.

For RS open burning emissions, the activity data that represents the amount of RS subjected to RS open burning (Mk) was calculated using Equation 7.2 below.

$$M_k = P_k \times S_k \times D_k \times B_k$$

P_k = Crop production for crop type k (mass amount per year, in consistent unit with M_k)
S_k = Crop-specific residue-to-production ratio
D_k = Dry matter-to-crop residue ratio (fraction, 0-1)
B_k = Fraction of dry matter residues, that are burned in the field (0-1).

The rice production per year (P_k) in 2015 value was obtained from national statistics (NIS 2016; OAE 2016; GSO 2016) while other parameters in Equation 7.2 were taken from the surveys conducted in this project.

To quantify the potential impacts of emissions on climate forcing,[1] the GWP of the emissions was calculated in term of CO_2 equivalent for the 20-year time horizon. The values used for the GWP calculation of different emission species were taken from the literature and selected to represent Southeast Asia (Fuglestvedt et al. 2009). In addition to GHGs, the climate forcing of SLCPs was also included in the GWP of the base case and scenario emissions. The amount of RS subjected to RS open burning (biomass loading) in 2015 for the three countries were calculated from the field survey results. Finally, energy consumption was calculated using the energy content of fuel in conjunction with CS efficiency to estimate the amount of solid fuels that could be replaced by RS-derived solid fuels for cooking.

Two emission scenarios were considered:

- *Scenario 1*: RS open burning would be eliminated and the amount of collectible RS in 2015 would be converted into roped (bundles) using a rope-making machine. The roped RS fuel would be used as cooking fuel in IBCS.
- *Scenario 2*: RS open burning would be eliminated and the amount of collectible RS in 2015 would be converted into pellets used as fuel in GCS.

The emission reductions under each scenario as compared to the base case of 2015 were quantified for the co-benefit analysis. Both energy content and CS thermal efficiency were considered in the calculation of the total fuel consumption under the scenarios. Finally, based on changes in fuel consumption under the two emission scenarios, the reductions in emissions of toxic air pollutants, GHGs and GWP, as compared to the base case of 2015, were quantified. The results show the volume of emissions that could be avoided by implementing the measures under the two scenarios and the potential co-benefits for air quality improvement and climate forcing mitigation.

Results

Survey results

A summary of the survey results is presented in table 7.1. In Pream Chor, the majority of farmers produce a single crop of rice annually while in Bang Pla Ma and Huong Tra, farmers typically have adopted the practice of annual double rice cropping. Mechanical harvesters are extensively used in all study areas: more than 90 percent by mechanical methods alone in Bang Pla Ma and Pream Chor; a combination of mechanical and manual methods in Huong Tra. Open field burning of RS was practiced by 59–95 percent of the interviewed farmers in the survey areas, and is more prevalent in Bang Pla Ma and Huong Tra than in Pream Chor. In Vietnam, open burning was practiced more widely by farmers who used mechanical harvesting methods. In Pream Chor, farmers tended to collect RS for livestock feed (51 percent) or leave straw in the field to decompose (23 percent), hence only a small proportion (about 16 percent) of RS was subjected to open burning.

The moisture content of spread RS in freshly harvested paddies was typically 22–25 percent, but higher moisture content was obtained for RS in Huong Tra, Vietnam (55 percent). The moisture content dropped to about 8–9 percent after four to seven days of post-harvest exposure to solar radiation in the field. The residue-to-product ratio (S_k) ranges between 0.68–0.74, with the lower value measured in Pream Chor, and a higher value measured in Huong Tra. This parameter was used to estimate the amount of dry RS subjected to open burning using Equation 7.2.

Most of the surveyed households in Pream Chor district used fuelwood (78 percent). In Bang Pla Ma, however, liquefied petroleum gas (LPG) use dominated (90 percent) and only small proportions of households using charcoal (5 percent) and fuelwood (5 percent). A combination of LPG and other solid fuels appeared to be the dominant energy sources in Huong Tra district (77.5 percent) with a small

Table 7.1. Summary of the survey results

Parameter	Prey Veng, Pream Chor district, Cambodia	Suphanburi, Bang Pla Ma district, Thailand	Thua Thien-Hue, Huong Tra district, Vietnam
No. of households surveyed[a]	252	290	200
Crop cycle/ year	One: 51%, two: 46%, and three: 3%	Two: 98% and three: 2%	Two: 100%
Harvesting method	Manual: 9% Mechanical: 91%	Manual:2% Mechanical: 98%	Manual: 10% Mechanical: 53% Both manual and mechanical: 37%
Rice straw utilization	Animal feed: 51%, Onsite decomposition: 23%, Field burning: 16%, and Others: 10%	Field burning: 95%, and Others: 5%	Field burning: 59%, Cooking fuel: 19%, Mushrooms: 2.5% Others: 19.5%
Open burning type	Spread burning: 85% Pile burning: 15%	Spread burning: 100%	Spread burning: 99% Pile burning: 1%
Current fuel used for cooking	Fuelwood: 78%, LPG: 12%, biogas: 0.3%, electricity: 6.6%, and corn cobs: 3.1%	LPG: 90%, Charcoal: 5%, and Fuelwood: 5%	LPG only: 16.5% Fuelwood only: 3.5% Others (RS, rice husk) only: 2.5% LPG with other fuels (i.e. coal, fuelwood, etc): 77.5%
Moisture content of rice straw	Fresh after harvest: 23.5 ± 2.1% A week after harvesting: 8.4 ± 0.6%	4 days after harvest: 8.6 ± 0.3%	Fresh after harvest: 55 ± 8.5%
Residue to product ratio (S_k, for cut and collected RS)	0.68 ± 0.07	0.72 ± 0.42	0.74 ± 0.10
Grain yield (tonne/ha/ cycle)[a]	3.5 - 4.3	3.6 - 3.9	4.8
Biomass of dry cut/collectable RS, kg/m^2	0.67 ± 0.15	0.60 ± 0.48	0.49 ± 0.16

Note: [a] Grain yield was obtained from primary measurements, on a dry weight basis.

proportion of households using only LPG (16.5 percent) or fuelwood (3.5 percent). Loose RS and rice husk were also used by some households in the study area (2.5 percent). Based on the types of fuels used in 2015, the potential for substitution of RS-derived solid fuels for cooking appears to be more favourable in Pream Chor and Huong Tra than Bang Pla Ma.

Most of the interviewed farmers expressed their willingness to stop the practice of open burning if the following two conditions were present: first, a stable market to sell the rice straw, and second, technologies that can be made affordable and available to quickly collect rice straw from the field after the harvest to allow quick preparation of the soil for the next crop.

Farmers also showed interest in adopting RS-derived solid fuels and suitable cookstoves, and stated that they would adopt RS conversion technologies (into cooking fuel) if available. However, all the farmers were concerned with the costs associated with this alternative source of energy. The conversion of RS from waste to an economic product such as cooking fuel could be a potential solution to reduce open burning. However, more research is needed to develop suitable business models that the farmers or community members can adopt more easily.

RS and RS-derived fuel characteristics

The characteristics of the unprocessed/loose RS and RS-derived fuels produced are presented in table 7.2 based on the research conducted. The bulk density of loose RS was 30 kg/m^3. Manually prepared roped RS (handmade) increased the bulk density to 57 kg/m^3 while machine-roped RS had a bulk density of 85 kg/m^3 (table 7.2). Cold densification produced briquettes with a density of around 13–21 times that of the loose RS. The highest densification factor of 20–25 times was achieved by the pelletizing process (table 7.2).

It can be seen that the properties of loose RS and manually roped RS based on the approximate analysis were quite similar, showing that the process would not affect RS properties. The moisture content of the RS-derived fuels was in the range of 8–10 percent, except for the RS pellets, which had the lowest moisture content (4.6 percent) due to the heat generated during the pelletizing process. The volatile content of the RS-derived fuels ranged between 63–71 percent, while the ash content ranged between 10–15 percent. The fixed carbon content of all types of

Table 7.2. RS-derived fuels: Bulk density and properties, approximate analysis

Type of fuel	Bulk density (kg/m^3)	Moisture content (%)	Volatile content (%)	Fixed carbon (%)	Ash content (%)
Loose RS[a]	29.9 ± 0.9	9.4 ± 1.1	65.0 ± 0.8	10.6 ± 0.5	15.0 ± 0.7
Manual-roped RS[a]	56.6 ± 3.9	9.1 ± 0.5	64.9 ± 0.9	11.0 ± 0.8	15.0 ± 0.5
Machine-roped RS[b]	85.0 ± 0.7	8.0 ± 0.01	68.0 ± 0.1	14.0 ± 0.2	10.0 ± 0.1
RS briquettes[c]	383-620	10.3 ± 0.1	64.1 ± 0.2	11.6 ± 0.4	13.4 ± 0.2
RS pellets[d]	605-736	4.6 ± 0.8	71.0 ± 2.0	11.8 ± 0.9	12.0 ± 1.2

Sources: Values from the project results by AIT team: [a] Mai (2015), [b] Donnapa (2016), [c] Rahaman (2015), [d] Cuong (2016).

densified fuels were in the range of 11–14 percent. The machine-roped RS had somewhat different properties than other fuels presented in table 7.2, due to the fact that loose rice leaves were more difficult to feed into the machine, hence the roped RS contained less leaves and more RS stems.

Thermal efficiency and emission testing

The measured emission factors (EFs) and thermal efficiencies of different types of RS-derived fuel-CS are presented in table 7.3. Among the four systems tested in this project, the highest thermal efficiency of 25 percent was achieved with machine-roped RS-IBCS followed by manual-roped RS-IBCS of 13.2 percent and by manual-roped RS-BCS of 12 percent. The loose RS-tripod had the lowest efficiency of 7.6 percent. The emission testing results for the four fuel-CS systems conducted by this project showed that the machine-roped RS-IBCS system produced the lowest EFs for all pollutants. Emission factors for benzene, toluene, ethylbenzene and xylenes from the machine-roped RS-IBCS (Donnapa 2016) were: 110–194 mg/kg, 27–76 mg/kg, ND–3.09 mg/kg, and ND–13.9 mg/kg (ND: not detected), respectively.

Table 7.3. Rice straw-derived fuel-CS systems: Thermal efficiencies and emission factors

RS-Cookstove (CS) system	Thermal efficiency (%)	EFs (g/kg)			
		CO	$PM_{2.5}$	CO_2	CH_4
Loose RS - tripod[a]	7.6	44.0	5.8	1,093	3.3
Manual-roped RS-BCS[a]	12.0	46.0	5.7	1,117	3.0
Manual-roped RS-IBCS[b]	13.2	37.0	3.9	1,285	3.6
Machine-roped RS-IBCS[b]	25.0	34.0	2.1	1,015	2.9
RS-GCS[c]	33.0	17.0	0.6	2,171	1.0

Sources: Values from the project results by AIT: [a] Mai (2015) and [b] Donnapa (2016); [c] values compiled by Jetter et al. (2012) for various biomass pellets and GCS; BCS: biomass cookstove, IBCS: improved BCS.

For the RS pellet-GCS, secondary data were compiled from literature for biomass pellets burned in a GCS (Jetter et al. 2012) which showed an average thermal efficiency of 33 percent. The lower EFs of pollutants but higher emission factors of CO_2 for this system compared to other systems (presented in table 7.3) suggest better fuel combustion conditions and hence lower emissions of the products of incomplete combustion, e.g. CO, CH_4 and PM. All the data generated were used to calculate the emissions changes for the co-benefit analysis under two scenarios.

Fuel consumption scenarios

The aim of this project was to alleviate emissions due to RS open field burning, hence the fuel-CS systems that offer higher efficiencies and lower pollution emissions were selected for the scenario analysis. Accordingly, the machine-roped RS-IBCS was proposed for Scenario 1 and RS pellet-GCS was proposed for Scenario 2. The survey results (table 7.1) were used to estimate the amount of RS subjected to open burning in Thailand and Vietnam, as compared to Cambodia (table 7.4). This study assumed that there was no open burning and all collectible RS in each country would be used as fuel/derived fuel for cooking to substitute for other solid fuels. The first priority for replacement was fuelwood, for which a reduction in consumption can also contribute to reduced deforestation. If there is RS remaining, then it would replace coal (fossil fuel), and then charcoal use, in each of these countries.

The thermal efficiencies of the existing fuelwood and charcoal used in various traditional CS in Thailand and Vietnam were obtained from Bhattacharya et al. (2002) while for coal-fueled CS in Vietnam, the value was taken from a study (1996) by the United Nations Development Programme (UNDP) and Energy Sector Management Assistance Program (ESMAP). For the roped RS-IBCS, thermal efficiencies were taken from measurements by Mai (2015) and Donnapa (2016) while for the pellet-GCS system, the efficiency was obtained from Jetter et al. (2012). Consumption of different types of fuel for cooking in each of the three countries and their potential replacement by RS-derived fuel under the two scenarios are detailed below.

Figure 7.4. Proposed fuel-CS systems for 2 scenarios

a) Scenario 1: Machine-roped RS + IBCS (Efficiency: 25%)

b) Scenario 2: RS pellets + GCS (Efficiency: 33%)

Scenario 1 (RS open burning would be eliminated and the amount of collectible RS in 2015 would be converted into roped RS produced by a rope-making machine). The machine-roped RS would be used as cooking fuel in IBCS (fig. 7.4a). Under Scenario 1, in Thailand, the useful energy of machine-roped RS (burned in the IBCS with thermal efficiency of 25 percent) would be sufficient to replace 100 percent of fuelwood used in the traditional CS (13.3 percent efficiency, Bhattacharya et al. 2002) and 100 percent of charcoal in a conventional charcoal cookstove (17.5 percent efficiency, Bhattacharya et al. 2002). The remaining RS energy of 20 percent could be made available for other uses. Using the same calculation

Table 7.4. Fuel consumption in cooking and RS open burning: Modeled scenarios, 2015

Scenario	Fuel consumption, Gg/yr					
	RS open burning[a]	RS-derived fuel[b]	Wood[c,e]	Coal[c]	Charcoal[c]	Remaining RS,%
Base case 2015						
Thailand	13,355	0	8,526[e]	0	4,386[e]	
Vietnam	26,276	0	20,447	2,404	601	
Cambodia	830	0	3,745	0	883	
Scenario 1: Roped RS + IBCS						
Thailand	0	13,355	0 (100%)[d]		0 (100%)[d]	20
Vietnam	0	26,276	0 (100%)[d]	0 (100%)[d]	0 (100%)[d]	46
Cambodia	0	830	2,219	0	883	
Scenario 2: RS pellets + GCS						
Thailand	0	13,355	0 (100%)[d]	0	0 (100%)[d]	40
Vietnam	0	26,276	0 (100%)[d]	0 (100%)[d]	0 (100%)[d]	59
Cambodia	0	830	1,731	0	883	
Changes in fuel consumption under scenario 1						
Thailand	13,355	13,355	8,526	0	4,386	
Vietnam	26,276	26,276	20,447	2,404	601	
Cambodia	830	830	1,526	0	0	
Changes in fuel consumption under scenario 2						
Thailand	13,355	13,355	8,526	0	4,386	
Vietnam	26,276	26,276	20,447	2,404	601	
Cambodia	830	830	2,014	0	0	

Notes: [a] Amount of RS subjected to open burning was estimated using Equation 2. [b] Assuming that 100% of RS subjected to open burning was converted to RS-derived fuels, hence no amount left for open burning in the scenario emissions. [c] Data retrieved from: https://knoema.com/UNSDESD2016/un-statistics-division-energy-statistics-database-2016. [d] The % in brackets indicates the portion of the 2015 fuel consumption replaced by RS-derived fuel. [e] Values for Thailand are from Thailand Department of Alternative Energy Development and Efficiency, http://www.dede.go.th/ewt_news.php?nid=42079.

method, 100 percent of fuelwood, coal (tradional CS with a thermal efficiency 15 percent) and charcoal, respectively, used in Vietnam could be replaced by the amount of roped RS while the remaining 46 percent of RS energy can be used for other purposes. In Cambodia, the available RS could only replace 41 percent of fuelwood.

Scenario 2 (RS open burning would be eliminated and the amount of collectible RS in 2015 would be converted into pellets to be used as cooking fuel with GCS). The pellet-GCS system is presented in figure 7.4b. Under Scenario 2, in Thailand, RS pellets burned in a GCS (33 percent efficiency) would replace 100 percent of fuelwood and charcoal, respectively. Higher thermal efficiciency of the pellets-GCS system would consume less fuel, hence more RS can remain for other uses (40 percent). In Vietnam, the available energy of produced RS pellets could replace 100 percent of all fuel types used in residential cooking with even more RS (59 percent) remaining for other uses. In Cambodia, 54 percent of the fuelwood can be replaced by the produced RS pellets. It can be seen that, as compared to emission Scenario 1, the RS pellets-GCS proposed in Scenario 2 has a higher efficiency, hence more solid fuels can be substituted in Cambodia, while in Thailand and Vietnam, the amount of RS left over for other uses would be higher.

Co-benefits of using RS-derived fuels for cooking

The changes in the emissions were quantified according to the changes in the fuel consumption under the two scenarios as compared to the base case of 2015. Table 7.5 presents the emission reduction by the implementation of scenarios 1 and 2, respectively, with simultaneous elimination of the practice of open burning in the three countries. In Vietnam, significant emission changes occurred because of a larger amount of RS available for producing RS-derived solid fuels to substitute the solid fuels used for cooking in the base case. Under both scenarios, the total reductions of toxic pollutants and GHGs, respectively, were 2.7 Tg and 39 Tg for Vietnam, while the corresponding values for Thailand were 1.5 Tg and 23 Tg. Less emission changes were obtained for Cambodia, as expected, because the amount of RS-derived solid fuels produced (by elimination of the RS that was subjected to open burning) were only sufficient for a partial replacement of fuelwood consumption in residential cooking. The total reductions under Scenario 1 were 0.16 Tg of toxic air pollutants and 2.3 Tg of GHGs, and higher reductions were seen for Scenario 2, i.e. 0.22 Tg toxic pollutants and 3.1 Tg GHGs for Cambodia.

Table 7.5. Emission changes: RS-derived fuels for cooking under two scenarios, no open burning (Gg/yr)

Species	Thailand		Vietnam		Cambodia		Total	
	SC-1	SC-2	SC-1	SC-2	SC-1	SC-2	SC-1	SC-2
CO	973	973	1,875	1,875	118	156	2,967	3,005
NOx	6	6	7	7	0.3	0.4	13	13
SO_2	12	12	7	7	0.01	0.02	19	19
NMVOC	99	99	199	199	14	18	312	316
PM_{10}	11	11	27	27	2	3	40	41
$PM_{2\text{-}5}$	96	96	134	134	8	10	238	240
NH_3	90	90	118	118	6	9	214	217
BC	11	11	27	27	2	3	40	41
OC	21	21	25	25	1	2	48	48
CH4	229	229	257	257	12	16	498	501
Total toxic pollutant mass[a]	**1,547**	**1,547**	**2,676**	**2,676**	**164**	**216**	**4,387**	**4,439**
CO_2	23,215	23,215	38,593	38,593	2,365	3,122	64,174	64,930
N_2O	1	0.51	1.33	1.33	0.09	0.12	1.9	2.0
Total GHG mass	**23,216**	**23,216**	**38,594**	**38,594**	**2,365**	**3,122**	**64,176**	**64,932**
GWP-20yr[b]	54,390	54,390	105,131	105,131	6,963	9,191	166,484	168,712

Notes: SC-1: scenario 1 (Machine-roped RS-IBCS); SC-2: scenario 2 (RS pellets-GCS); [a] OC and EC are included in PM mass; [b] GWPs of SLCPs and GHGs are included in this total GWP value

The GWP of the emissions (in CO_2 eq) for the 20-yr horizon were also calculated to evaluate the potential benefits introduced by the scenarios for climate forcing mitigation. The reductions in the GWP 20-yr emission in CO_2 eq were 54 Tg, equally for both scenarios for Thailand, while the value for Vietnam would be almost double, 105 Tg. Smaller reductions could be realized for Cambodia, i.e. 7.0 and 9.0 Tg of CO_2 eq under scenarios 1 and 2, respectively. Collectively for all three countries, under Scenario 1, a reduction of 166 Tg of CO_2 eq would be achieved, while under Scenario 2, a slightly higher reduction of 169 Tg CO_2 eq would be achieved.

Discussion

The surveys conducted by the project team revealed the status of RS management in Cambodia, Vietnam and Thailand. Multiple rice crop cycles are evident in Vietnam and Thailand, two to three crop cycles per year, as compared to the prevalence of a single crop cycle in Cambodia. In the survey areas of Cambodia, only 16 percent of interviewed households practiced open burning. This proportion increased to 59 percent in Vietnam while in Thailand most of the farmers (95 percent) practiced open burning. Several factors contributed to the lower proportion of open burning in Cambodia, e.g. the use of RS for animal feeding (51 percent) and RS in-field decomposition (23 percent). Most farmers in the target area in Cambodia had livestock and those who did not, could sell the RS to farmers who raised livestock. In particular, in-field decomposition was possible in this area because the single cropping cycle per year would allow enough time for the RS to decompose before the next crop is sown. The more common off-site uses of RS for cooking and mushroom growing in Vietnam also reduced the percentage of households practicing open burning; in the survey area of Thailand, no substantial off-site uses were reported.

Mechanical harvesting is more common in Cambodia and Thailand than in Vietnam. The use of mechanical harvesters spreads RS across the fields, making it more difficult to collect, and hence open burning is more commonly practiced in Cambodia and Thailand. With manual harvesting methods, however, the RS is collected along with the harvested grains. The rice straw is then separated and piled in a corner of the paddy field and burned. The survey results confirmed that burning of spread RS (spread burning) is commonly done in all the survey areas of these three countries.

Spread burning generated less emissions per kg of RS burned than pile burning, which tends to smoulder over an extended period and produce more smoke (Kim Oanh et al. 2011).

As they become wealthier, farmers are seen to have a tendency to practice open burning (Cao et al. 2008). This is particularly so because gas stoves become affordable for these farmers and there is minimal use of RS for cooking purposes. Also, in order to maximize the number of crop cycles per year, the farmers practice open burning as it is the fastest way to get rid of the “unwanted” biomass to prepare the soil for the next crop. Depending on demand and climate conditions, farmers in the three countries can have more than one rice crop cycle per year (table 7.1).

Farmers are aware of the harmful effects of the smoke from open burning, however, they feel that open burning only takes place over a short period each year. They ignore the fact that “short open burning” occurs in a number of places in the same area during the same days which results in high air pollution levels. When discussing the potential health effects from exposure, most farmers agreed to stop open burning if they had viable alternatives that allowed for quick removal of RS and its use for other purposes such as cooking fuel. In particular, farmers who use fuelwood for cooking were interested in using RS-derived solid fuels if they cost less. But farmers were less concerned about any potentially adverse impacts of open burning on the soil quality and crop yields.

Some farmers were also concerned about the need to return nutrients back to the soil by allowing the straw to decompose in the field after harvest. In this case, the off-site use of RS seems not to provide benefits. However, only the cut portion of the rice straw would be collectible from the field for off-site use while the standing RS (20–30 percent of the total above-ground biomass estimated from our survey results) would still remain in the field for decomposition. In addition, on-site composting of all produced RS (both cut and standing parts) can be practiced only when there is a sufficient gap between cropping cycles. The ploughing and on-site composting (with enzymes added) method has been promoted in Thailand, but has not gained popularity among farmers due to several factors, including the need for more labor (when compared to open burning), and powerful ploughing machines. Moreover, on-site composting also requires a longer fallow period to prepare the land for the next crop (Kanokkanjana and Bridhikitti 2007).

The current study has found that pelletizing and briquetting produced highly densified fuels with a densification factor of 13–25 times compared to manual or machine roping that increased density by only 2–3 times above that of loose RS. The densification methods did not significantly change the properties of RS-derived fuels. Handling processed RS products is easier in terms of storage and transport compared to the loose RS. But the key remaining challenge is the collection of rice straw from the paddy fields after the harvest. Innovative research is needed to develop technologies that can collect and convert RS into processed fuels on-site, for example, by following the mechanical harvesting machines.

Suitable cookstoves should be selected to specifically burn the RS-derived solid fuels. The improved biomass cookstove (IBCS) prepared in this project for burning roped RS can increase thermal efficiency while producing lower emissions than traditional BCS: the machine-roped RS-IBCS system can achieve a 25 percent efficiency with relatively lower emissions. The selected GCS can efficiently burn the RS pellets with a high thermal efficiency of 33 percent and lower emissions of toxic pollutants (products of incomplete combustion). The portable gasified cookstove (GCS) is available in the market and is convenient to use. It is, however, more expensive than the IBCS, hence may require a subsidy to make it affordable for farmers in the Mekong Region.

Emission changes due to the elimination of open burning and substitution of solid fuels with RS-derived solid fuels in residential cooking under both scenarios were significant. Large volumes of toxic air pollutants (including SLCPs) and GHGs emissions could be avoided. Turning RS into cooking fuel may incentivise farmers to stop open burning given the economic value of RS-derived fuels. Reducing dependency on fuelwood for cooking would also help to reduce deforestation. In Vietnam, there is significant potential for utilizing RS biomass resources and this could be managed in order to avoid open burning and associated emissions. In Cambodia, the amount of available RS subjected to open field burning is less than in Thailand or Vietnam (given that there is generally only a single crop cycle per year, and that RS has other uses, as shown in table 7.1). Significant emissions reductions can still be achieved in Cambodia by avoiding open burning. In addition, as compared to the burning of RS-derived fuels in selected CS, RS field open burning emits larger amounts of toxic pollutants in principle because of uncontrolled combustion conditions (Kim Oanh et al. 2011; Kim Oanh et al. 2015).

The analysis of the emissions changes indicates that the measures proposed under Scenario 1 and Scenario 2 to eliminate open burning would significantly contribute to reductions in toxic air pollutants (also SLCPs) and GHGs hence bring about significant co-benefits in air quality improvement (subsequently to human health, crops and ecosystems) and climate forcing mitigation (GWP 20-yr in CO_2 eq). These measures would also have other benefits, including reducing the deforestation rate by lowering fuelwood consumption for cooking as well reducing expenditure on other solid fuels. Further studies are required to analyze all the costs and benefits of the RS-derived solid fuels, as well as to develop a business model which involves the production of RS pellets and the production and selection of suitable cookstoves for the region.

Conclusions

The study's findings included the following:

1. Open field burning of RS has been practiced for many years in the agrarian countries of GMS. Surveys conducted in this study confirmed that farmers in the selected agricultural areas in the three countries practiced open burning and the proportion of RS subjected to open burning depended on several factors, i.e. number of crop cycles per year, prevalent off-site uses of RS, and harvesting method (mechanical or manual).
2. In the places where farmers use fuelwood for cooking, they were willing to use RS-derived solid fuels instead, while in areas where the use of LPG dominated, adoption would be contingent on cost.
3. Pelletizing and briquetting methods were able to produce highly densified RS-derived solid fuels with a densification factor of 13–25 times that of loose RS, while roped RS had a densification factor of 2–3.
4. Machine-roped RS-IBCS can achieve 25 percent efficiency with lower emission factors of pollutants than the manual-roped or loose RS burned in traditional BCS. The RS pellet-GCS has a high efficiency of 33 percent and produced lower emissions of toxic air pollutants, but greater amount of CO_2 due to more complete combustion.
5. Under both scenarios, the roped RS burned in IBCS would be more than sufficient to substitute 100 percent of the solid fuel consumed

in the residential sector in Thailand and Vietnam. The remaining RS, of which there is more under Scenario 2 due to the higher thermal efficiency of the pellets-GCS, can be used for other purposes. In Cambodia, however, only a part of the fuelwood currently used for cooking could be replaced by available RS.

6. The use of RS-derived fuels and the selected CSs can help to eliminate open burning and produce significant co-benefits in reducing emissions of toxic air pollutants, GHGs, and GWP 20-yr.
7. Training and workshops on the adverse effects of open burning on human health, soil quality and crop yield, along with the climate effects, should be targeted at farmers because they are the most important stakeholders in adopting non-open burning alternatives.
8. Further research should aim to develop convenient ways to collect and convert RS into cooking fuel, preferably on-site in paddy fields, and create a business model to realize its potential benefits. Other non-open burning alternatives such as on-site composting, mushroom growing, etc., should also considered.
9. The governmental boundary partners have been very supportive in providing information related to their policies on open burning while nongovernmental (NGO) partners were keen on sharing their experiences of CS testing and the promotion of clean CS. The involvement of boundary partners in the project provided an efficient way to convey the project's key findings.
10. The science-based information provided in this project should be disseminated to policymakers to intervene and eliminate the practice of post-rice harvest open burning in GMS countries and beyond.

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Note

[1] See further National Oceanic and Atmospheric Administration, US Department of Commerce, Climate forcing, *Climate.gov*, https://www.climate.gov/maps-data/primer/climate-forcing (last accessed May 14, 2019).

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8

Linking disaster recovery approaches and loss and damage systems in the Mekong Region

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The Mekong Region has historically suffered devastating disasters and continues to experience regular loss and damage on a large scale. Of particular concern are the changing frequency, intensity and distribution of climate-related hazards in the region: extreme events such as floods, tropical cyclones and droughts make the region one of the most at-risk in the world (Kreft et al. 2016; Garschagen et al. 2016; UNESCAP 2017). While climate change and El Niño are important external drivers of the frequency, intensity and spatial distribution of these hazards, other socioeconomic, political and environmental factors drive the underlying vulnerability of at-risk populations in the region (IPCC 2012; UNDP and UNESCAP 2017; Thomalla, Boyland and Calgaro 2017). Among these so-called "root causes" of disaster risks are poverty and inequality, rapid and unplanned urbanization, natural resource degradation, weak governance institutions and non-risk-informed policies (UNGA 2015).

Effectively managing and reducing disaster and climate risks is a key challenge for the Mekong Region, and needs to be a priority issue for government agencies at all levels and other key actors working across the region. Various policies and actors are concerned with reducing disaster impacts, but are limited in their effectiveness due to a short-term, *ex post* perspective that prioritizes managing and responding to events. Further, flood risk management is typically the responsibility of water resource management (WRM) sector actors, rather than being a holistic, multi-sector effort that considers how risks are created (and can be reduced) across all sectors (Chau et al. 2014; Lebel and Lebel 2017). Insufficient and ineffective disaster risk reduction (DRR) can lead to more frequent and worsening disaster events, with complex and prolonged recovery phases. This chapter seeks to understand the recovery processes and loss and damage systems present in the region, and how separate approaches can become more integrated, through analysis of three flood disaster recoveries in Cambodia, Thailand, and Vietnam.

"Loss and damage" has long been the subject of debate in climate policy circles, initiated by the Small Island Developing States (SIDS) demanding compensation for the impacts of climate change, especially sea level rise (Calliari 2016). Such roots mean the term is largely thought of as highly political and a polarizing force between developed and developing countries in climate negotiations (Vulturius and Davis 2016). Yet, over time, loss and damage has found its place in climate change policy discourse. At the Conference of the Parties (COP) in 2013, a dedicated body was established to promote and support the implementation of approaches to address loss and damage, and the Paris Agreement, adopted at COP21 in 2015, includes an article on loss and damage (UNFCCC 2013, 2015). That said, at the insistence of developed country parties, the Paris Agreement calls for "action and support" on loss on damage, rather than compensation. At the 2017 COP23, several observers were dissatisfied with the slow progress and lack of commitment to the Paris Agreement article on loss and damage, including the lack of financial resource mobilization (Chandrasekar 2017; Serdeczny 2017).

Away from international climate policy and United Nations Framework Convention on Climate Change (UNFCCC) mechanisms, understanding and addressing loss and damage has been taken up by research and practice communities including those working on adaptation and DRR. However, with no "official" definition or common framework to work from, a range of perspectives on loss and damage have emerged (James et al. 2014; Boyd et al. 2017). An early UNFCCC loss and damage paper does broadly define the term as "the actual and/or potential manifestation of impacts associated with climate change in developing countries that negatively affect human and natural systems" (UNFCCC 2012: 3), but leaves several aspects open to interpretation (James et al. 2014).

One critical unanswered aspect concerns how (in)distinct loss and damage approaches are from adaptation, DRR and development approaches (e.g. Mechler and Bouwer 2014; Roberts et al. 2015; Boyd et al. 2017). As efforts to reduce climate loss and damage move from the negotiation halls to the communities on the frontline, greater clarity and understanding of loss and damage in relation to existing efforts to reduce impacts and risks is vital. Here, we consider loss and damage systems, which are defined as the formal and informal institutions, processes and systematic actions which aim to assist communities and societies to absorb, cope with, adapt to and recover from adverse effects of disasters that may be either irreversible (loss) or replaceable (damage) (see Thomalla et al. 2017). A better understanding of the performance of loss and damage systems and disaster recovery approaches is needed to cope with and adapt to the long-term impacts of climate change (Surminski and Lopez 2014).

Recognizing the ambiguity and diversity in the loss and damage discourse, Boyd et al. (2017) identify a typology of four perspectives, presented as a spectrum of viewpoints. The risk management perspective refers to an opportunity for linking adaptation, DRR, humanitarian and development action in a comprehensive, holistic risk management framework. An isolated loss and damage approach or mechanism is considered a hindrance to effective risk management and resilience building (ibid.). One specific crossover between the *risk management* perspective on addressing loss and damage and the broad DRR/disaster management field concerns recovery from climate change-related disaster impacts. Disaster recovery, defined by the United Nations (UNGA 2016: 21) as "restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster- affected community or society," is also closely associated with resilience and with "building back better." As an *ex post* risk management approach, disaster recovery finds great complementarity in loss and damage mechanisms that aim to address "actual loss and damage," rather than prevent "potential loss and damage" (see Boyd et al. 2017). However, in-depth, empirical, studies of the synergies and trade-offs between loss and damage mechanisms and disaster recovery approaches are lacking. This is surprising given the long-standing discourse on linking climate change adaptation and DRR science and policy (e.g. Schipper and Pelling 2006; Thomalla et al. 2006; IPCC 2012). Boyd et al. (2017) suggest the loss and damage framing can enable much-needed analysis of whether traditional DRR approaches can address evolving climate risks, both extreme events and slow onset processes.

In this chapter we explore the links between disaster recovery approaches and loss and damage systems through case study research of major flood disaster recoveries that have occurred in the Mekong Region in recent years. Specifically, we draw insights from three empirical case studies:

1. The economic recovery of small and medium enterprises (SMEs) in Bang Bua Thong (BBT) market, Nonthaburi province, Thailand, following the 2011 flood event;
2. Residential cluster and socioecological resilience-building approaches in Prey Veng province, Cambodia, following the 2000–2001 flood; and
3. Strategies for living with regular floods and livelihood recoveries of farmers in An Giang province, in the Vietnamese Mekong Delta (VMD), following the 2000 flood.

Through these case studies, we respond to three research questions:

1. What loss and damage systems exist in major flood disaster recoveries in the Mekong Region?
2. What lessons for improving loss and damage systems can be learned from major flood disaster recoveries?
3. How can loss and damage systems and disaster recovery governance, approaches and practices be pursued in greater harmony?

Methodology

The three case studies selected for analysis of disaster recovery processes and loss and damage systems pertain to some of the most severe flood events to have occurred in the Mekong Region, in terms of human and economic impacts, in recent decades (CRED and Guha-Sapir 2017), and are known to have had extensive, multifaceted recovery processes and loss and damage systems. While each flood event affected a large area spanning multiple provinces in each country, the case studies are localized to focus on areas that were among the most acutely impacted districts and communities. The case studies are diverse in terms of actual losses and damage, timing, length of recovery period, recovery governance system, and national economic development context, thus an overarching analytical framing and common qualitative methodology was used to ensure consistency for cross-comparison. A case study protocol was co-developed and updated by case study researchers to guide each iteration of data collection and analysis. This protocol defined key terms, stated the research questions, described the research design and guided data collection and analysis. The protocol was translated into the local languages of each of the three case studies.

The qualitative methodological approach consisted of literature review and document analysis, interviews with key actors and stakeholders in each case study, and research analysis and synthesis workshops, conducted between 2014 and 2017. Literature review and document analysis established the state of the scientific and practical knowledge on disaster recovery approaches, loss and damage systems, and the case studies contexts. Literature searches were conducted using the scientific database Scopus and internet search engines Google and Google Scholar. Relevant publications and documents, written in English and in the local languages of the case studies, were archived in Zotero. In each case study, between 20 and 30 key informant interviews were conducted with officials and planners in authorities that governed the recovery processes; researchers and technical experts; representatives of donors, aid agencies, international and local nongovernmental organizations (NGOs) engaged in the recovery; and leaders, organizers, businesses and members of affected communities.

The first case study analyzes the recovery of SMEs in BBT market in Nonthaburi province, Thailand, following the 2011 extreme flood event. The 2011 flood event was one of the worst disasters to ever affect Thailand, causing close to 1,000 deaths, affecting 10 million people, and leading to huge national economic losses of approximately US$40 billion (CRED and Guha-Sapir 2017; World Bank 2012). One economic sector acutely affected was the SMEs. There are approximately 2.7 million SMEs contributing 37 percent of the gross domestic product (GDP) and accounting for 80 percent of the workforce in Thailand (ADB 2014). In BBT market, Nonthaburi province, economic impacts were particularly severe and have persisted since the flood; this has been compounded by a weak national economy in recent years (Marks and Thomalla 2017).

The second case study evaluates resilience-building efforts and new residential cluster schemes in Prey Veng province, Cambodia, following consecutive extreme monsoon flooding events in 2000 and 2001. The floods were the worst to hit Cambodia in more than seventy years, accounting for more than 400 deaths and affecting five million people across almost the entire country, resulting in significant economic losses (CRED and Guha-Sapir 2017). Impacts were particularly severe in provinces in proximity to the Mekong River and Tonle Sap lake, including Prey Veng, where hundreds of houses and kilometers of roads were destroyed. A large agricultural area was damaged or lost, causing food shortages for around one million people. In response, the Royal Government of Cambodia, the Cambodian Red Cross, and humanitarian NGOs provided short-term emergency aid to affected provinces. The National Committee for Disaster Management (NCDM) was established to lead and coordinate disaster management efforts in Cambodia. Similar bodies were established at provincial and district levels.

The third case study examines farmers' recovery and capability to live with floods in An Giang province, in the VMD, following the 2000 flood event which caused 500 deaths and affected five million people—one of the worst disasters to have affected the delta area in decades. An Giang province is one of the most flood-prone provinces in Vietnam, and indeed in the Mekong Region, due to a range of natural and man-made factors (Le et al. 2007). The concept of "living with floods" emerged as a national government strategy following the 2000 disaster, and key programmes included building "flood-proof" houses, enhancing flood release capacity, and shifting crop calendars (Tinh and Hang 2003). The VMD plays a key role in terms of food security and socioeconomic development of the Mekong Region, but is a densely populated area with high flood risk and vulnerability. Without effective risk management, this risk is expected to increase as the sea level rises, land use changes and urbanization rates accelerate (Garschagen et al. 2011).

Results

Loss and damage systems in major flood disaster recoveries

Across the three case studies results a total of 14 loss and damage system initiatives were identified and are categorized according to five recovery sectors—livelihoods, infrastructure, financial, institutional, and ecological, aligned with disaster recovery frameworks (e.g. FEMA 2017; GFDRR

2015). Table 8.1 summarizes the presence of loss and damage system initiatives in each case study, and below we describe some key examples, paying particular attention to whom they target, when they were active, and how they were initiated and implemented.

Table 8.1. Loss and damage system initiatives present in each case study, categorized by recovery sector (grey = presence of initiative)

Recovery sector category	Loss and damage system initiative	Economic recovery of SMEs, Nonthaburi, Thailand	Residential cluster and building resilience, Prey Veng, Cambodia	Living with floods and farmers' recovery, An Giang, Vietnam
Livelihoods	Rehabilitation			
	Stimulus			
	Transformation			
Infrastructure	Reconstruction			
	Protection			
	Shelter			
Financial	Compensation			
	Insurance			
	Community funds			
	Loans/micro-credit			
Institutional	Professional associations			
	Local institutions			
Ecological	Ecosystem services for DRR			
	Ecosystem services for livelihoods			

Livelihoods

Some type of livelihood or sector stimulus policy has been pursued by all of the national and local governments of the case study countries. In Thailand, efforts focused in particular on supporting the automobile manufacturing industry, and lower income groups buying their first car through the new car tax rebate. Reducing interest rates, raising the minimum wage and the salaries of government officials, tax exemptions to foreign investors, and the construction of flood protection infrastructure implemented through the Flood Management Plan were other measures taken by the Government of Thailand to enable economic recovery. However, the government did not provide any targeted assistance to help SMEs recover.

In Vietnam, the "living with floods" policy approach enabled the introduction of a third rice harvest and training on alternative off-farm activities for additional income during the flood season. In Cambodia, alternative livelihood training was meant to support people to find other income-generating activities. The degree to which affected households and businesses employed alternative livelihood options varied. SMEs in BBT didn't make any changes to their business operations, but continued to sell the same goods with the same strategies. Elsewhere, people derived additional income from off-farm activities and growing additional crops (Vietnam) or migrating to the city and borrowing from moneylenders and micro-finance schemes (Cambodia).

Infrastructure

The infrastructure recovery category encompasses a range of loss and damage initiatives. Protective infrastructure projects implemented in Thailand included raised roads, walls around industrial estates, flood embankments along waterways, and changes in the management of dams. However, no changes to land-use planning were found. In Vietnam, efforts focused on the Residential Cluster Program with a full and semi-dike system. In Cambodia and Vietnam, roads and bridges were upgraded to protect people from flooding and to enable improved access to jobs, healthcare facilities and schools. Infrastructure measures were also taken at the individual and household levels, for instance, installing improvements to homes and businesses. In Thailand, this included the raising of shop floors, moving merchandise upstairs during the rainy season, moving the office to the back of the house, and ordering less inventory during the monsoon season. In Vietnam, the quality and location of houses were improved through the frame-house design introduced by the Residential Cluster Program. In Cambodia, people also rebuilt their homes to ensure that they were raised above expected flood water levels.

Financial

Financial initiatives included compensation, insurance, and community funds and loans/micro-credit. In Thailand, compensation was problematic and contested, which led several thousand people in BBT to protest for more transparency and fairness in its distribution. Food for work programs and the provision of food and basic building materials occurred in Cambodia. In Vietnam, compensation for households affected by disaster were available at the local level for a death or injury in the family, and for damages to or losses of property and crops. Insurance played a role only in Thailand, where some SMEs had purchased cover before the floods and received pay-outs, and others who had no cover during the event purchased cover afterward. However, the number of people who purchased insurance was small, and a good proportion discontinued it after only two or three years, believing that their houses would not be flooded again. The availability of funds at the community level were important aspects of the financial loss and damage systems in Vietnam and Cambodia. In Vietnam, banks provided loans to farmers for land purchases and house construction. In Cambodia, farmers were able to access loans for house construction from micro finance institutions, and micro-credit for house repairs was made available to the poorest farmers through informal community networks.

Institutional

Local community-based institutions played an important role in all cases. In Thailand, the Market Association prepared community disaster preparedness plans. In Cambodia, the Disaster Association supported poor people affected by the floods by giving them material assistance such as food and basic building materials. In Vietnam, local institutions assisted affected people during the first three days of the floods, under the "four on-the-spot disaster management policy" (*Phương châm 4 tại chỗ*) which concerns mobilizing local forces for immediate response. In Vietnam, importance is also given to cultural memory and local knowledge on anticipating weather conditions that might lead to a flood disaster.

Ecological

Ecological loss and damage systems pertain to the provision of ecosystem services for DRR or livelihood support, and were found relevant to all cases. In Thailand, one issue was that few natural floodwater retention areas, such as wetlands and retention ponds, existed at the time of the 2011 flood event. Some are being implemented, but for the purpose of reducing water shortages during droughts. The "living with floods" approach in Vietnam aimed to accommodate rather than control floods through the use of semi-dikes that allow occasional and controlled floods which replenish soil nutrients for fertility. In Cambodia, ecosystem-based approaches in disaster recovery included the diversification of cropping varieties and the creation of fisheries communities tasked with the restoration of fish production and the fish catch, and the protection of riverbanks from soil erosion.

Discussion

Improving loss and damage systems in disaster recovery contexts

The case study research has identified loss and damage system initiatives present in major flood disaster recovery processes in the region. Drawing on the presented case study results and supplementary literature, we discuss limitations and barriers in the governance of loss and damage systems, and suggest opportunities to overcome them.

First, there was limited downward accountability of loss and damage systems in all cases. One reason for this is that governance structures in these countries remain centralised. National governments have retained the major share of decision-making power and resources in order to protect national interests. Despite this, national government agencies can become overwhelmed and respond ineffectively and inefficiently following a major disaster, for instance in the wake of the 2011 flood event in Thailand (Marks and Thomalla 2017). Second, fragmented governance arrangements of loss and damage systems in recovery contexts limit collaboration, and even cause unintended negative consequences of attempted recovery interventions. One reason for this is because individual agencies seek to protect their mandates and budgets (Marks and Lebel 2016). Participation is a key facet of ensuring accountability and maintaining transparency, but government agencies tend to exclude key groups of both recovery actors and beneficiaries in some contexts. For example, SMEs were largely sidelined despite the major role they play in Thailand's local and national economies. The delegation of recovery implementation responsibilities to sub-national levels is recommended for effectiveness and efficiency (GFDRR 2015). Third, the agency capacity and resources for working on disaster management remains insufficient, with a general focus on short-term disaster response action rather than long-term recovery and resilience-building approaches. As a result, limited financial and human resources have been devoted to multi-hazard, comprehensive DRR that connects with broader development efforts.

Given such limitations, how can these systems be improved? We suggest six recommendations. First, the legal foundations of DRR policies and practices need to be more institutionalized since they currently create uncertainty regarding agencies' DRR responsibilities in these countries, which particularly come to light during complex, high-pressure recovery phases (see also Chau et al. 2014; Marks and Lebel 2016). Second, a more devolved, participatory and cross-level decision-making system, that engages all levels of government as well as external agencies and NGOs, is needed. Disaster-affected people whose disaster risk and development futures are being shaped by loss and damage system initiatives should be central to post-disaster decision-making processes. Third, multi-agency and multi-scale inclusion needs to be ensured in ways that avoids duplication of effort. Overlaps in mandates, particularly in the WRM sector, is common in the Mekong Region (see Lebel et al. 2005) and needs to be minimized for the sake of effective disaster recovery governance. Fourth, while agencies and practitioners are encouraged to incorporate "building back better" principles in recovery visions and frameworks, more needs to be done to advance understanding of the term to go beyond "principles" and in practice to represent more than reconstruction of infrastructure and housing. A heavily structural-focused recovery strategy may simply redistribute rather than reduce risk (Lebel and Sinh

2009). Fifth, clear guidelines, milestones and agency responsibilities for transitioning from recovery to development are required in major disaster recovery contexts, particularly in terms of feeding into existing land-use planning and WRM policy. Development policy must also be flexible and adaptive to anticipate major disaster recoveries, which may shift development priorities, possibly even for the better. Sixth and finally, considering these limitations in recovery governance, disaster-affected communities should not remain passive but rather they should self-organize to provide social safety nets to those worst affected, become active voices in planning processes, create their own early warning systems, and advocate for targeted loss and damage assistance during disaster recoveries. Table 8.2 summarizes the discussed limitations and opportunities for loss and damage system governance in recovery contexts.

Table 8.2. Limitations and barriers in the governance of loss and damage systems in disaster recovery contexts, and opportunities to overcome them

Key limitations / barriers	Consequences	Opportunities to overcome the limitation / barrier
Insufficient resources	• Limited action • Incomplete implementation	• Effective budget/trust-fund management • Delegate implementation responsibilities to sub-national levels • Link with private-sector action
Ineffective planning	• Key services not provided in timely fashion	• Leverage ongoing development initiatives for recovery (e.g. social services) • Utilize inter-agency task forces
Lack of accountability and transparency	• Corruption • Poor coordination • No long-term responsibilities	• Prioritize transparency in recovery decision-making • Balance trade-off between accountability and bureaucracy • Institutionalize monitoring & evaluation, long-term reviews
Social injustice in recovery programmes	• The most vulnerable marginalized • Poverty not addressed • Socioeconomic inequality	• Target assistance and safety nets to most vulnerable • Ensure participation in decision-making processes • Mainstream gender and social equity principles in loss and damage systems

Towards integrated loss and damage systems and disaster recovery approaches

The impacts of disasters, as demonstrated here, can be compounded by insufficient loss and damage systems and ineffective disaster recovery approaches. When disaster management and governance systems are not equipped to cope with and adapt to disaster events of a magnitude that exceeds expected or "normal" levels, people suffer deeper consequences. The post-disaster phases of response and recovery are critical for determining how severely and for how long a disaster will impact people. Our results highlight that loss and damage systems play an important role in disaster recoveries, but they tend to be thought of as distinct approaches from one another. Here we discuss the differences and commonalities between disaster recovery interventions and loss and damage systems, and consider options for greater harmonization of the two approaches.

The first point of divergence for loss and damage and disaster recovery approaches comes at the international policy level. As noted, the concept of loss and damage is rooted in international, UNFCCC-framed climate change negotiations and mechanisms. Disaster recovery, meanwhile, is arguably a less political-driven term that is more rooted in experienced impacts of disasters and efforts to recover from lost and damaged assets to a state of normality again. At all levels, climate change and disaster management governance are typically divorced from one another. At the global level, the UNFCCC orchestrates legally-binding climate change policy for all parties (i.e. the Paris Agreement), while the United Nations Office for Disaster Risk Reduction is unable to secure the same level of commitment from nations to tackle disaster risks; the 2015-adopted Sendai Framework for Disaster Risk Reduction (UNGA 2015) is a non-binding policy framework document. Further, the two policy processes do not sufficiently recognize one another as complementary and working towards mutual goals, in the broader context of the Sustainable Development Goals (SDGs). In the Mekong Region, national level governance arrangements are similarly fragmented and siloed; climate change is typically framed and governed as an environmental issue, while flood risk management is a WRM sector concern (e.g. Chau et al. 2014; Marks and Lebel 2016; Lebel and Lebel 2017). Recovery actors must improve integration and collaboration beyond the limits of institutional arrangements and mandates. A priori recovery institutionalization is a key enabler of effective processes and interventions (GFDRR 2015).

In recent years “build back better” has emerged as a widely adopted goal of disaster recoveries—originally articulated by former US president Bill Clinton in the aftermath of the 2004 Indian Ocean Tsunami (in his capacity as UN Special Envoy for Tsunami Recovery) (UN 2006). Although “building back better”—using a disaster as an opportunity to improve societies—is clearly a desirable goal, some argue that this is a narrative owned by powerful international interests that have politicized disaster recoveries at the expense of the empowerment of those affected, who may have very different priorities (Fan 2013; Thomalla et al. 2017; Boyland et al. 2017). This also links to the broader counter-narrative of disaster capitalism by the state and private actors (Loewenstein 2015; Klein 2007). Disaster recovery and loss and damage actors alike can work together to ensure that post-disaster initiatives follow inclusive, people-centered approaches and decision-making processes where the power is not concentrated in the hands of a few officials.

While we are not arguing for a reinvention of the wheel, given the layer of risk that climate change adds to disaster risks, the DRR community, including recovery actors, must take account of these changing risks in their approaches. Disaster recovery approaches are typically short- and medium-term in nature, but would be enhanced by taking a longer-term view of disasters and climate change, and seeking to better link with resilience and development actions (Mosel and Levine 2014; Thomalla et al. 2017). GFDRR (2015) suggest that linked resilient recovery and development integrates gender equity, vulnerability reduction, natural resource conservation, environmental protection, and climate change adaptation. Boyd et al. (2017) argue the framing of loss and damage can facilitate better integration of adaptation and DRR approaches. Common ground for such integration may lie in realigning both approaches to holistically tackling the root causes of risk that are generated within unsustainable development processes (UNISDR 2015; Thomalla et al. 2018).

Conclusions

This chapter has analyzed loss and damage systems in disaster recovery processes following major flood events in Thailand (2011), Cambodia (2000–01) and Vietnam (2001). Through empirical case study analysis we have also highlighted where disaster recovery and loss and damage system approaches to disaster and climate risk reduction converge and diverge. A diversity of systems and interventions were found, in terms of livelihoods, infrastructure, financial, institutional, and ecological recovery sectors. This reflects both the severity of the disaster impacts and the diversity of actors working in different loss and damage systems as part of major disaster recoveries in each of the three case studies.

While important support and services were provided to affected communities in each of the cases, loss and damage systems can more effectively build resilience by considering the underlying drivers of vulnerability, how to equitably reach intended beneficiaries and societal groups (e.g. women, children and persons with disabilities), and overarching governance constraints such as the effectiveness, coordination and accountability of national and local authorities together with international and national NGOs.

Loss and damage systems and disaster recovery interventions have several commonalities and differences, but the results of the case studies suggest that the approaches could be pursued in greater unison. Both approaches can learn lessons from one another in order to ensure that climate and disaster risks are addressed in harmony, by taking a multi-risk and longer-term approach when recovering from disasters. The Mekong Region is a global "hot spot" for climate and disaster risks, and actors at all levels need to address the conflicts created by fragmented institutional arrangements and power imbalances to ensure the long-term resilience and sustainability of the region's people and environments.

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9

Climate change and water scarcity in Champhone district, Savannakhet province, Lao PDR

Saykham Voladet and Chansathit Chaleusinh

Evidence is mounting that Lao PDR is vulnerable to climate change and water scarcity (Phaivanh 2011; ADB 2014). The country's relatively small economy, limited industrial base and high dependence on agriculture (most of it still subsistence-oriented), remain constraints on national efforts to improve key socioeconomic development indicators. Given this context, the government requires extensive climate adaptation studies that can help both inform and improve its socioeconomic policies and achieve its overall goal of sustainable development while emerging from its least developed country (LDC) status by 2020 (MAF 2015).

This chapter uses the site of Champhone district in central Laos as a case study of climate change and water scarcity impacts. This district is located in the hottest and driest part of the country and is highly vulnerable to climate variations and water shortages (Phaivanh et al. 2011). Champhone is also an important contributor to the national economy as well as having ecological and socio-cultural sites of importance that require conservation. Agriculture is the core economic activity of the district in a key food production region of Savannakhet province and the country as a whole, with approximately 1.5 million people relying on the agricultural outputs from the district.

The research objectives of this study were to analyze the specific physical/natural attributes, infrastructure development, socioeconomic activities, and cultural elements of the study areas and their exposure to climate change and water scarcity; assess plausible trends of climate change and water scarcity using local observations and historic climate data, and climate projections generated through various climate models;

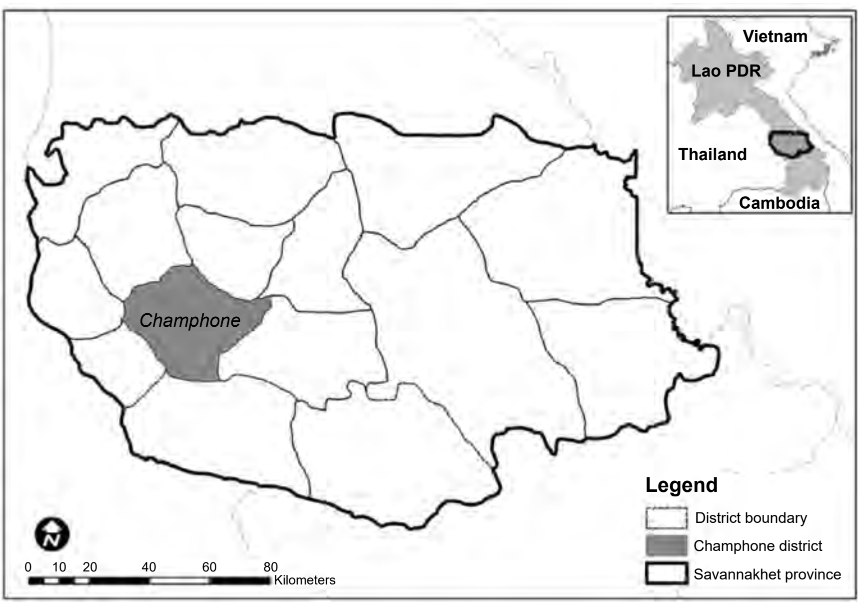
review the potential impacts/implications of projected climate change and water scarcity on physical/natural sites and infrastructure and socioeconomic and cultural characteristics; and identify possible pathways of adaptation to climate change and water scarcity through multi-stakeholder engagement.

The approach taken in achieving these objectives included: a review and synthesis of the relevant literature; two technical consultation workshops, with key stakeholders and line agencies; structured key informant interviews; focus group participatory assessments in four randomly selected communities; a structured survey of 162 randomly selected households in the four communities; and in-depth interviews of four household heads affected by climate change and water shortages.

Study area

Champhone district is located about 54 km southeast of the provincial capital, Savannakhet. It shares borders with seven districts of Savannakhet province (fig. 9.1).

Figure 9.1. Location of Champhone district, Savannakhet province, Lao PDR



Champhone district lies on a flat plain within the Xe Champhone River Basin, at an altitude of about 900 m above sea level. The difference in elevation between the north (Sakhun village) and south (Khoklo village) of the district is a mere 10 m, a factor that contributes to the prolonged retention time of surface waters and inundation during heavy rainfall and floods.

Approximately 12 ha of the Xe Champhone River Basin in Champhone district falls within the Xe Champhone Wetlands that was designated as a Ramsar Wetlands Site in 2010 due to its conservation importance. Furthermore, several sites of natural, ecological, historical and cultural significance are located in the district.

The district is located in the hottest and driest part of Lao PDR (GoL 2011) with an average mean temperature of 26.13°C and an annual precipitation of 1,478.5 mm (table 9.1). Data from one meteorological station shows that the district over the past 41 years (1975–2015) has witnessed significant fluctuations in temperatures and rainfall. According to a long-term trend of this time series data, the mean annual temperature increased by 0.05°C while rainfall declined by approximately 5.85 mm annually (table 9.1 and fig. 9.2).

The district has a total population of 105,415 composed of four culturally distinct ethnic groups: Lao, Puthai, Mangkone, and Katang. The Lao and Puthai share the same religion, have similar cultures, and constitute 80 percent of the population. The Katang and Mangkone have similar cultures and their combined coverage makes up the remaining 20 percent of the population. The district has a relatively young population, comprising 40 percent under 15 years old; approximately 55 percent that make up the economically active labor force, i.e. between 15 and 65 years of age for men and between 15 and 60 for women; and 5 percent over 65. The dependence ratio (the proportion of people of non-working age to those of working age) is estimated to be 0.8, which is relatively low (Champhone DOPI 2004).

Over 80 percent of the working population is engaged in agriculture, including crop farming, livestock rearing, and fishing. Some 10 percent are employed in the service sector, including the retail trade, local government (civil servants), local transportation services, and car and motorcycle repair shops. About 5 percent work in handicrafts and industry, including rice processing mills, sawmills, furniture workshops, and bottled water plants and cement factories. The remaining 5 percent of those of working age are still in school or tertiary institutions.

Champhone district has a relatively well developed economy compared to many other districts in the country. The average per capita income is estimated to be about Lao Kip (LAK) 14.5 million (US$1,768 per year), which includes income derived from agriculture (rice and vegetable farming, fishing and livestock rearing). However, from an overall country perspective, income inequality in the district is relatively high. The GINI-coefficient is estimated to be 74 percent with over 25 percent of the population living under the international poverty line,[1] meaning they have expenditure and consumption of less than US$1 per person per day.

Approximately 73.8 percent of household income is derived from the agricultural sector, mainly from rice, vegetables, fruits and livestock production along with fishing. The largest share of agricultural production is for household consumption using traditional methods of production. Approximately 12.7 percent and 13.5 percent of income is derived from services and industry/handicraft. A dominant share of the industries and services are small-scale household businesses. Because the region is so dependent on the agricultural sector, the economy of Champhone district is vulnerable to the impacts of climate change and water scarcity.

Methodology

Literature review and synthesis

The research team collected, reviewed and analyzed a number of studies and reports including, but not limited to, annual socioeconomic reports and plans of Champhone district and Savannakhet province as well as a range of related study reports on social and environmental issues affecting farmers. In addition, the research team collected and analyzed local climate data from a meteorological station in the district and studied long-term climate projections from the available climate models that included A_2, B_2 (SEA-START 2010) and the Atmospheric General Circulation Model (AGCM) (GoL 2009) to assess future trends in climate change, with a particular focus on the implications for water resources and water scarcity.

Technical consultation workshops

During the research, two technical consultation workshops were organized with the participation of key local/district agencies/offices including various district offices, mass organizations (Youth Union and Women's Union), and farmers' associations.

The first technical consultation was convened at the beginning of the project to discuss a plan for the case study including study methodologies such as participatory assessment (PA), key informant interviews and household surveys. The second workshop was organized after the field data collection, analysis and drafting of the case study report. The main purpose of the second workshop was to discuss and inform participants of the preliminary research findings and seek comments and suggestions for improvements.

Key informant interviews

Interviews with key informants were conducted to gather missing detailed information and statistical data that were not readily available from the literature review and consultation workshops. In addition, these interviews provided insights into our understanding of climate change on the various sectors and policies on water scarcity adaptation. In total, the research team met and interviewed 12 key people or experts who had a good understanding of climate change in their location, including representatives of the district offices for natural resources and environment, agriculture and forestry, planning and investment, health, labor and social welfare, finance; and representatives of local organizations, farmers' associations and individual farmers. Findings from the key informant interviews were an important source of information to assess the potential impacts of climate change and water scarcity in the study location.

Focus group discussion/participatory assessment (PA)

Focus group discussions were conducted in four randomly selected communities including Kadane, Khampanea, Piaka and Pakua villages. In each community/village, two focus group discussions were organized. The first group comprised representatives of local authority, including the village head, deputy heads, representatives of village youth organization, women's organization, village national front, and heads of local administrative units. The second group was a diverse group composed of elderly, respected individuals and people having relatively high formal educational level. Between five to seven people participated in each group. The main purpose of these focus groups was to collect qualitative information on climate change and water scarcity impacts and help improve understanding of the impacts of adaptation at the community level.

Household surveys

Household surveys were conducted in the four randomly selected communities described above. The main purpose of the surveys was to collect statistical data and information on climate change and water shortage impacts as well as to improve our understanding on how farmers attempted to adapt to a changing environment. A total of 162 households were randomly selected for the survey. The survey captured detailed information on household demographics, income, income sources, expenditure, assets, and experiences with extreme events related to climate change and water scarcity over the past five years. In addition, individual views were collected on how to adapt to climate change and water scarcity impacts. The survey used a questionnaire designed specifically for this case study.

In-depth interviews

In-depth interviews were conducted in the four selected communities selecting one or two household heads who were most affected by climate-related events like sudden floods and extended periods of drought during the last five years. The main purpose of these interviews was to collect information on: perceptions of reasons for vulnerability to extreme weather events, methods of adaptation used to mitigate the impacts of such events, early warning and emergency assistance systems, and the nature of emergency assistance received during a climate-induced crisis.

Key findings

Historical climate change

The findings from the focus group discussions, key informant interviews, and analyis of local historical climate data show that Champhone district has experienced significant climate change and water scarcity over the past 40 years. This is reflected in temperature increases and a decline in rainfall (table 9.1 and fig. 9.2). Findings from the analysis of historical climate data indicate that the average temperature at the recording station has increased by 1.9°C and the rainfall declined by around 239.85 mm over the past 41 years (1975–2015) (table 9.1 and fig. 9.2). The mean temperature has increased by approximately 0.05°C annually which is in line with previously published data, and rainfall has been declining by 5.71 mm annually (table 9.1 and fig. 9.2).

The analysis of data about long-term average rainfall over the past 41 years indicates that periods of drought and water shortages should have increased and flood events should have declined. However, in fact, it is not the case. Focus group discussions indicated that floods now occur every year in the study area with different degrees of severity, length, and coverage. The focus groups reported that the severity of floods has increased and participants attributed this to declining forest cover, shallower rivers and ponds due to sedimentation, and heavy rainfall within a short period.

According to findings from the analysis of historical climate data, the onset of rains has also changed over the past 41 years. Rainfall in June and August declined by 3.1 mm (1.4 percent) and 5.5 mm (1.6 percent) on average per annum, respectively, while rainfall in May and July increased by 1.25 mm (0.7 percent) and 1.3 mm (0.5 percent) per annum on average, indicating a high percentage of change. The intensity of both rainfall and flood events has also shown an increasing trend over the past 41 years (table 9.1 and fig. 9.2).

There was a general consensus among local interviewees and discussants that climate change has had significant impacts on physical and natural sites and resources as well as on local livelihoods in Champhone district.

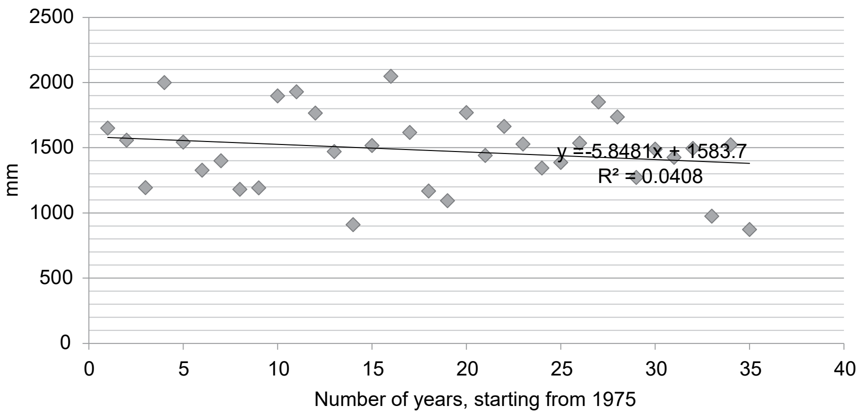
Table 9.1. Forty-year trends (1975–2015) in selected climatic data collected from a recording station in Champhone district, Savannakhet province

Items	Unit	Average during 41 years (1975–2015)[a]	Change during last 41 years[b]	Average yearly change[c]	P-value[d]
Temperature					
Average mean temperature	°C	26.13	1.90	0.055	0.0007
Average maximum temperature	°C	31.4	1.40	0.045	0.0175
Average minimum temperature	°C	21.8	3.10	0.087	0.0038
Average temperature in March	°C	25.5	3.20	0.09	0.013
Average temperature in April	°C	27.6	1.80	0.05	0.014
Average temperature in May	°C	28.4	1.80	0.057	0.0018
Rainfall					
Annual rainfall	mm	1,478.50	-239.85	-5.85	0.024
January	mm	1.5	2.87	0.07	0.02
February	mm	19.9	3.69	0.09	0.04
March	mm	32.4	64.37	1.57	0.12
April	mm	62.6	-7.38	-0.18	0.0005
May	mm	178.5	51.25	1.25	0.003
June	Mm	228.7	-127.1	-3.1	0.065
July	mm	274.3	53.3	1.3	0.06
August	mm	344.8	-225.5	-5.5	0.02
September	mm	247.9	-65.6	-1.6	0.039
October	mm	78.6	-20.5	-0.50	0.005
November	mm	8.4	22.55	0.55	0.09
December	mm	0.9	8.2	0.2	0.04

Notes: [a] The entire duration was 41 years (Champhone DOPI 2015). However, some observations were not or incompletely recorded. Therefore, we have to drop them out from the analysis in order to minimize bias; [b] The difference between linear regression in 2015 and 1975 (Champhone DOPI 2016); [c] slope of the linear regression; dP-value of the linear regression.

Source: Derived from data provided by the Savannakhet Provincial Department for Agriculture and Forestry.

Figure 9.2. Long-term trend in selected data on annual rainfall, Champhone district, Savannakhet province



Source: Savannakhet Provincial Department for Agriculture and Forestry data.

Climate projections for Champhone district

Due to a lack of human resources and technological constraints, Lao PDR does not have the capacity to undertake climate model projections for long-term climate change. However, the country receives information from regional climate projection centers, particularly from the Southeast Asia Center for the Global Change SysTem for Analysis, Research and Training (SEA-START) located in Bangkok, Thailand.

SEA-START developed different climate models to project climate change in the Mekong Region, including Lao PDR, Thailand and Vietnam. The climate projection scenarios and climate model used in this study include A_2, B_2 and AGCM respectively. However, according to information provided in the National Adaptation Plan for Action (NAPA), all of these projections are currently at an early stage in their development, thus there is still significant uncertainty associated with model outputs (GoL 2009: 20).

The SEA-START scenarios indicate that Champhone district will be subject to moderate climate change with an increasing mean annual temperature of between 0.51°C–0.7°C by 2050. These temperature increases are based on scenario A_2, which projects an increasing mean temperature of between 0.51°C and 0.6°C, and scenario B_2, which projects an increase in the mean temperature of between 0.61°C and 0.7°C. (Pokhrel et al. 2018: 16 fig. 5; Phaivanh et al. 2011).

These results from scenarios A_2 and B_2 are relatively small compared with the same projections made by AGCM that project mean temperatures in the Mekong Region as a whole increasing by 2.6°C by the end of the twenty-first century (Pokhrel et al. 2018: 16 fig. 5) and it is also lower compared with the increasing mean temperatures that have been observed at the meteorological station in Champhone district over the past four decades (1.9°C) (table 9.1 and fig. 9.2).

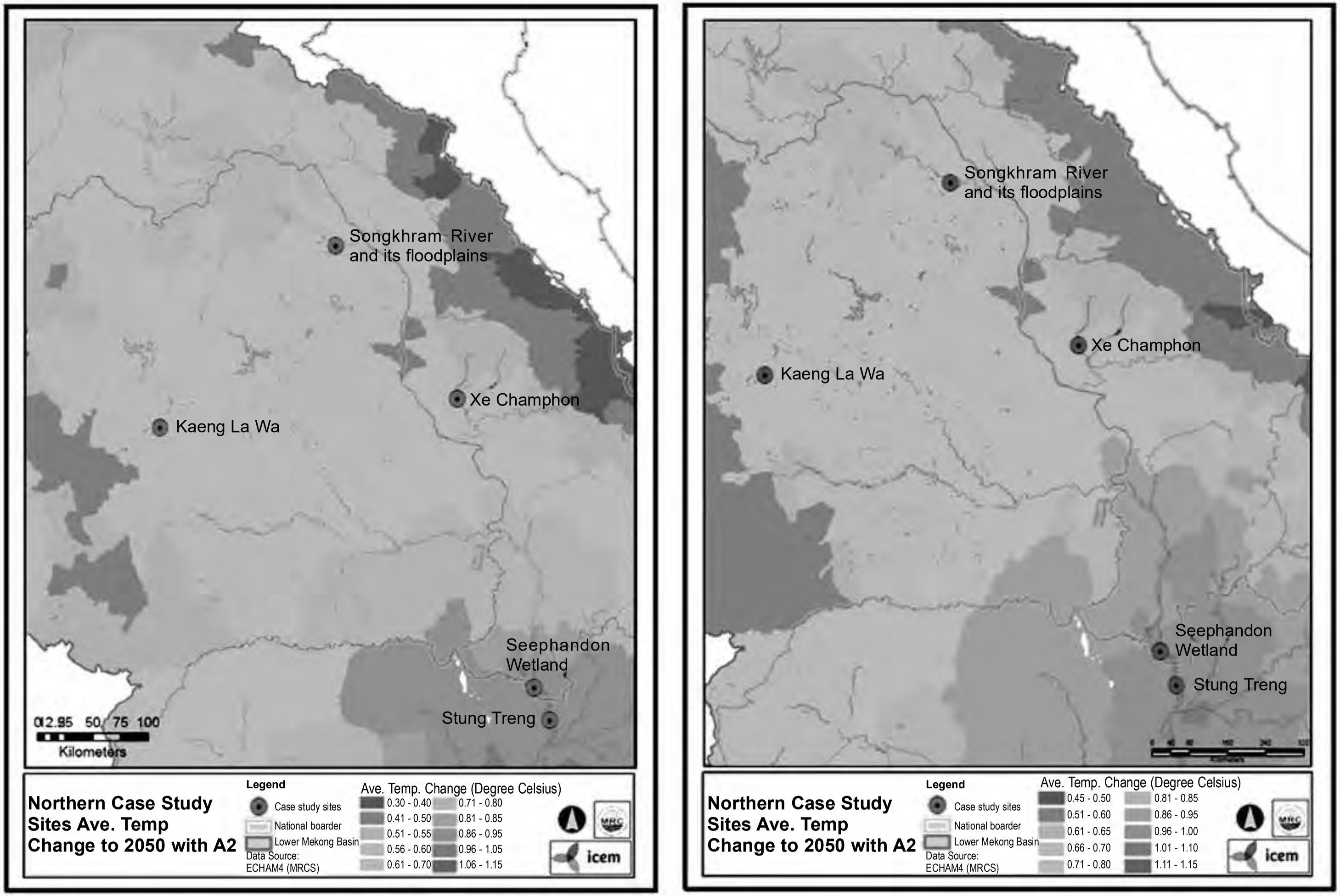
With respect to rainfall, the climate model for scenarios A_2 and B_2 projected that annual rainfall in Champhone district would increase by approximately 14 percent, that is equivalent to an increase in rainfall of 255 mm by 2050 (Phaivanh et al. 2011) while the AGCM projected that it would increase by only 4.2 percent across the region by the end of the 2100 (GoL 2009). The scenarios A_2, B_2 and AGCM projected that the increased rainfall would be caused predominantly by an increase in the intensity of rainfall events and not by an increase in the length of the wet season.

There is still a high degree of variability and uncertainty between the respective models in predicting future temperatures and precipitation for Champhone. However, by analyzing outputs of climate scenarios A_2, B_2 and AGCM this study found a general climate trend that all of the climate scenarios have also commonly predicted. According to the model outputs, Champhone district will likely experience higher temperatures and increased rainfall intensity; the wet season will be wetter and shorter, while the dry season will be dryer and longer (fig. 9.3; Pokhrel et al. 2018: 16 fig. 5). Thus the severity and intensity of both floods and droughts is expected to increase.

Potential impacts of climate change and water scarcity

In this sub-section, an assessment on impacts of projected climate change on physical/natural sites and resources as well as on socioeconomic and cultural characteristics/elements of the case study site is discussed. The first part focuses on assessing the impacts on physical/natural sites and resources, while the second focuses on assessing the impacts on local livelihoods.

Figure 9.3. Average mean temperature changes under scenarios A_2 and B_2 in Champhone district, Savannakhet province (Phaivanh et al 2011)



Physical/natural sites and resources

Hydrological system: Evapotranspiration and temperature are projected to increase and thus lead to a decline in the total water quantity particularly in the dry season. This could cause the volume of water in rivers, pools and ponds in the area to decrease with a greater degree of isolation between water bodies, or to completely dry out (fig. 9.4a). Hotter and longer dry seasons are also expected to increase water evaporation from soil and contribute to lowering stored soil moisture with the potential for increased secondary salinization, given that the region has primary salts stored at a depth in the profile associated with natural salt deposits (Phounprakon 2011). Further increased evaporative demand could reduce the amount of replenishment of groundwater (Phaivanh et al. 2011). The increasing ambient temperature combined with the longer and dryer dry seasons are expected to increase invasive plant species, resulting in the drying out of small wetlands and other temporary water bodies (fig. 9.4b). This would reduce the capacity of these natural structures to store and release water in the wet season.

Further, the Xe Champhone River system has unstable, loamy river banks, which are susceptible to erosion. An increase in rainfall intensity and runoff in the wet season can be expected to increase soil erosion into the river which then further exacerbates riverbank erosion with the river becoming wide and shallower, leading to the development of blockages that will constrain water flows. These impacts combined together will worsen the impacts of flooding and inundation (fig. 9.4c, d).

Habitats and biodiversity: Increasing soil erosion due to surface runoff during the monsoon season and subsequent delivery to the river are expected to result in deposition in deep pools, reducing their depth and impacting the habitats of many fish species (fig. 9.4a, b). Changes in the wetlands from open to closed flows due to mats of invasive plants will also contribute to a loss of biodiversity as many species of fish such as tilapia and eel require open wetlands to survive (fig. 9.4b).

Isolated wetland sites that are the habitats of endangered species such as turtles and the Siamese crocodile will also be affected. These isolated wetlands are approximately 2 ha wide and the anticipated increases in temperature would dry out the wetlands and cause a decline in water quality, all of which will negatively impact these endangered species' habitats (fig. 9.4a).

Figure 9.4. Impacts from climate variability on hydrological system in Champhone district, Savannakhet province. a: Turtle pond, a small-isolated wetland inhabited by an endangered turtle species; b: invasive plant species closing off the open wetlands; c: riverbank erosion; d: development of blockage constraining water flow and affecting deep pools, making the river shallower (January 12, 2016).

Ecosystem services: Increases in temperature as well as longer and dryer dry seasons will increase water evaporation from the soil and thus reduce soil moisture and productivity in the provision of non-timber forest products (NTFPs), including bamboo shoots, wild vegetables, medicinal plants and firewood (Phaivanh et al. 2011). Further increases in temperature together with longer dry seasons will also reduce the capacity of wetlands to supply and replenish groundwater. Further increases in erosion rates associated with more intense rainfall events will affect the water quality and associated ecosystems services of the river system. This will have implications for the provision of water of adequate quality for both irrigation and domestic consumption.[2]

Local livelihoods

Crop farming: Based on findings from the focus group discussions and key informant interviews, crop production in Champhone district is already being affected by climate change, particularly by increasing temperature, declining rainfall and the changing timing of the wet season. Climate change impacts predispose crops to water stress (fig. 9.5a) and associated pest infestation, facilitating the breeding of crop pests that feed on rice thereby affecting productivity.[3] Furthermore, it increases water evaporation from soil with corresponding secondary salinization (fig. 9.5c) and declines in crop productivity (Phounprakon 2011).

Figure 9.5. Droughts, floods and salinity affect rice production in Champhone district, Savannakhet province: a. drought-damaged rice field (Bui et al. 2015); b. flood-damaged rice field (Sivannakone 2014); and c. salinity-affected rice field (Phounprakone 2011).

The projected climate scenarios for Champhone district, particularly increasing precipitation, may mitigate the observed impacts that farmers are currently experiencing. However, this does not mean that predicted climate trends will facilitate crop production overall because farming, particularly wet season rice production, not only faces drought risk and water shortages during the growing season, but also inundation (fig. 9.5b). According to findings from a study conducted by the Mekong River Commission (MRC) in 2011, between 10–20 percent of wet season rice fields in the district are damaged by floods annually, causing huge economic losses (Phaivanh et al. 2011). The anticipated increased rainfall intensity is expected to exacerbate the current situation with economic implications for farmers due to crop losses.

Livestock production: Discussions with key informants from the Champhone District Office for Agriculture and Forestry indicated that increases in temperature and a decline in rainfall has already affected livestock production significantly, especially the rearing of large animals such as buffalo and cattle. Lack of clean water and a decline in feed production contributed to outbreaks of livestock diseases such as anthrax and diarrhea.[4] Large numbers of buffalos and cattle die every year because of illness and insufficient feed to sustain them over the longer dry season. Consequently, livestock farming of large animals in the district has steadily declined in recent years (table 9.2). Projected increases in temperature and longer dry periods are expected to further degrade natural grasslands and to increase water contamination, thereby exacerbating livestock diseases. In addition, increases in temperature and rainfall during the wet season are expected to increase humidity, contributing to the spread of livestock diseases and affecting overall animal health.[5]

Fishing: The projected increase in rainfall during the wet season is expected to improve fish habitats to some extent. However, this does not mean that the projected climate change will have positive impacts on local fisheries overall. Higher temperatures and longer and dryer dry seasons could promote the growth of invasive species and increase the size of thick floating vegetation mats that can clog waterways; along with the closing of wetlands, these will adversely impact fish habitats (fig. 9.4c). The closure of wetlands will have a significant impact on fish habitats. In addition, the late onset of the rains could constrain the breeding of some fish species (Phaivanh et al. 2011).

NTFPs and hunting: The projected increase in temperatures and longer and dryer dry periods are expected to increase water evaporation from the soil and affect NTFP habitats and growth, reducing food sources for wild animals (Bui et al. 2015). Similar to fishery impacts, NTFP collection and hunting of wild animals may no longer be a reliable source of additional food and income in Champhone district.

Human health: Sudden variations in seasonal climate increases the incidence of many diseases including diarrhea, amoebic dysentery, smallpox and cholera. According to statistical data provided by the Champhone District Office for Health, over 10,000 people in the district were affected by these diseases in the period 2010–15.[6] The Office expects that increased temperatures and rainfall in the wet season will increase humidity, facilitating the breeding of insect species including mosquitoes transmitting malaria and dengue fever, house flies transmitting diarrhea, and the spread of amoebic dysentery.[7] In addition, the projected increase in rain intensity is expected to increase negative impacts on water quality leading to the spread of diseases like smallpox, diarrhea, dysentery, and cholera. Households having little or no access to improved/protected water sources are at greater risk from climate-related health diseases.[8]

Dwellings, irrigation and road infrastructure: Because of its geographical characteristics, particularly the shallow gradient between the north and south, Champhone district is prone to floods of varying degrees of severity and coverage. Floods have damaged houses, irrigation channels and road infrastructure.[9] Champhone district has to expend a significant portion of its budget to repair the infrastructure damaged by floods every year.[10] The projected increase in rainfall, and rainfall intensity, is expected to worsen flood risk and negatively impact livelihoods.

Water sources: About half of Champhone's population uses water from wells and/or groundwater sources.[11] The increased temperature and declining rainfall over the past four decades has increased groundwater salinity in the water sources in some areas (Khamthao village) and consequently villagers have to purchase potable water. The projected climate trends are expected to further increase salinity. Furthermore, about one-third of the population uses rain water, spring water and water from rivers and ponds.[12] Increased temperature, and a hotter, longer dry season, could affect water quality and quantity; some springs, rivers and ponds may dry up, causing more water shortages in turn.

Adaptation to climate change and water scarcity

Climate change and water scarcity are already an existing problem and, according to findings from the literature review, key informant interviews and field observations, people in Champhone district have already started to adapt to their changing circumstances. Most of these measures are related to adaptation to drought and water scarcity. They include improved irrigation, through the construction of small-scale weirs, dikes and ponds by farmers, and the use of water pumps for irrigating rice seedlings (Outhevy et al. 2018). There has been increasing use of chemical fertilizers and pesticides (Phaivanh et al. 2011) and a switch from buffalo and cattle to smaller ruminant (goats) livestock that require less water and feed (table 9.2). In response to increased erosion from flooding, some communities have also planted bamboo along canals and paths (Bui et al. 2015).

Table 9.2. Changing livestock production in Champhone district, Savannakhet province, 2005–15

Livestock	2005	2010	2015
Buffalo	28,000	21,000	14,000
Cattle	34,519	28,100	26,200
Pigs	15,090	18,100	22,200
Goats	2,258	3,000	4,500
Poultry	211,350	368,000	415,100

Sources: Champhone DOPI 2006, 2011, 2016.

To address the decline in natural fish populations, people in Champhone district have increased the amount of time they spend fishing, varied the types of fishing gear they use, and built ponds for raising fish (Phaivanh et al. 2011). There are currently around 1,000 fish ponds covering over 100 ha in the district. Every year, millions of fingerlings are released into these ponds (Champhone DOPI 2015).

A further adaptation measure to cope with the increased difficulties of sustaining livelihoods from natural resources in the area is labor migration (Outhevy et al. 2018). According to focus group participants, significant numbers of people, particularly youth, migrate seasonally after the rice harvest to Savannakhet city or Thailand seeking jobs and/or income generation activities (Bui et al. 2015). The trend of labor migration is expected to increase along with regional economic integration, and given climate change, earning a livelihood based solely on natural resources may become more difficult to sustain.[13]

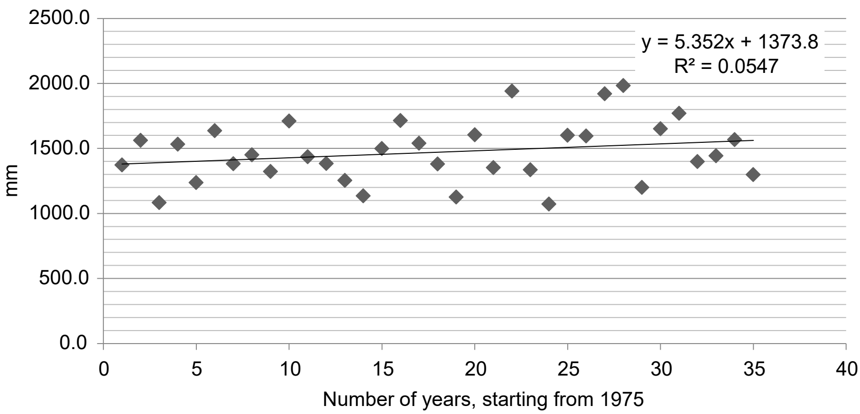
In addition, several adaptation measures are being evaluated and piloted by external organizations. For example, the MRC's Climate Change Adaptation Project Initiative (CCAI) evaluated strains of rice in Taleo village, analyzed soil types and certain plant species around Nakatang village and extended irrigation canals around Kengkok village (Sivannakone et al. 2014). The Wildlife Conservation Society (WCS) has provided irrigation pumps to local villages, built a number of small weirs and cleared vegetation from certain wetlands in order to improve crocodile habitats (Hedemark and Phothithay 2011).

Conclusion

This study assesses the impacts of climate change and water scarcity on physical/natural sites on livelihoods in the case study site as well as reviews existing adaptation measures in Champhone district. The strength of this assessment is that it involved many stakeholders in the research process, including representatives of district and provincial agencies, farmers' associations, local authorities as well as selected individual farmers and other qualified people living and working in the district. It also uses, analyzes and compares data and information from many sources. Therefore, the findings of this study are quite robust and have been widely accepted by the local stakeholders who attended our workshops and participated in the research.

A key finding of this study is that Champhone district has been experiencing declining rainfall during the last four decades. This climate trend is contrasted with the same ones at the provincial level of increasing precipitation during the same period (figs. 9.2 and 9.6). The findings from this study show that climate change impacts are very local; they depend on many factors, including the area's physical/natural and livelihood characteristics. Hence, climate analysis, impact assessments and adaptation policies should be based on local characteristics. A more general analysis, and broad-based impact assessment and adaptation policies may be inapplicable to local conditions in many cases.

Figure 9.6. Long-term trend of annual rainfall in Savannakhet province



Source: Savannakhet Provincial Department for Agriculture and Forestry data.

One limitation of this study is that it assesses the potential impacts of physical/natural sites and resources as well as livelihoods based mainly on the climate predictions of A^2, B^2 and the AGCM-model only. The study does not include other models that may provide different projected results for further comparison.

According to information provided in NAPA (GoL 2009), all of these models are still at an early stage of development and there remain significant uncertainties associated with their outputs. This provides a level of uncertainty to the climate predictions and poses a challenge for any future assessments or policy recommendations based on this study.

Another limitation of this study is that it tried to assess the potential impacts of predicted climate trends on key physical/natural sites and resources as well as on livelihoods based mainly on a literature review, key informant interviews, participatory assessment (PA) and observations made by the study team. Consequently, the results from the assessment are qualitative ones, with limited statistical indicators for quantifying the extent of the potential impacts. For example, this study assessed that the expected higher temperatures, and a hotter, longer and dryer dry period, would affect the water sources in terms of water quality and quantity, but was not able to provide any detailed information on the projected percentage of decline in water resources as a consequence of climate change. Therefore, further quantitative studies or impact assessments need to be continued on these topics.

Recommendations

To ensure necessary climate change adaptation in Champhone district, this study would like to recommend the following measures be taken:

Improving reservoirs and expanding the irrigation system: Based on projected climate change, the district will have more water in general although rainfall will be delivered over a shorter period. Improving the water storage capacity of existing reservoirs and creating more reservoirs would help to mitigate water shortages across the district. The water storage capacity of existing reservoirs such as Ang-Soui, Buk, Phai Chai Cheo lakes can be improved by clearing invasive vegetation species that are reducing the reservoirs' storage capacities and/or enhancing the height of dikes. In addition, over 6,000 ha of rice fields in Champhone district are still rainfed and lack access to irrigation, increasing their vulnerability to water scarcity (Champhone DOPI 2009). Improving reservoir storage capacity and expanding irrigation systems would assist farmers in adapting to water scarcity.

Developing and implementing an effective water and watershed management plan: Champhone district does not have an effective and clear water and watershed management plan that allocates and prioritizes water use and the protection of watersheds. An effective water and watershed management plan can help cope with periods of water security and lead to more efficient use of water resources.

Continuing and increasing research and development work to support climate change adaptation for the agriculture sector: Agriculture is the key livelihood activity and main income source in Champhone district.

This sector is significantly affected by climate change, particularly by droughts, floods, changes to rainy season timing, salinity, and pests. Hence, the sector needs to be assisted through increasing knowledge coproduction and associated support. There are very few research and development projects that are financed and driven by external organizations. The central government, local authorities and internal organizations themselves are not yet actively involved in the area. Research and development is needed, for example, to determine which plant and animal species are more resilient to climate variability, and whether new strains of rice or local species should be promoted. Studies on salinity should be conducted. Market demand and value chains for agricultural products that require less water are required.

Breeding, nursing and releasing native fish back into rivers, lakes and ponds: Climate change will negatively impact the breeding and survival rate of fingerlings of many native fish species, and thus contribute to the decline of fish populations, thereby affecting local livelihoods. Breeding, nursing and releasing native fish back into natural rivers, lakes and ponds will mitigate the negative impacts of climate change on fish populations and sustain local fisheries and livelihoods.

Promoting livelihood activities that are less directly dependent on climate change and water resources: Alternative livelihood activities should be promoted by measures such as providing short-term vocational training and/or promoting labor migration to the special economic zone (SEZ) in Savannakhet provincial center, cross-border labor migration, and the setting up of micro/household businesses in non-farm sectors, including in trade, tourism and handicraft production.

Increasing access to improved water sources and providing health advisories: Over 30 percent of responding households still use water from unimproved/unprotected sources, including unprotected springs, rivers, ponds, rainwater and wells, and over 42.9 percent of responding households stated that they still drink untreated raw water regularly or sometimes.[14] These households face a higher risk of exposure to water-borne diseases, such as diarrhea, dysentery, and smallpox. Projected rainfall intensity during the early part of the rainy season is expected to worsen water quality and increase the risk of exposure to water-borne diseases. Access to improved/protected water sources, as well as health warnings to encourage people to drink only safe water, are a cost-effective measure to reduce the risks of poor quality or hazardous water.

Improved sanitation: Over half the population in the case study area still does not have access to adequate sanitation facilities.[15] Thus, they have a higher risk of exposure to related diseases including diarrhea, dysentery, and cholera. According to information provided by the Champhone District Office for Health, thousands of people are often affected by these diseases every year. The projected increase in temperature would facilitate the breeding of houseflies that transmit these diseases. Improved sanitation will be an important adaptation measure.

Increasing social protection schemes in terms of coverage and benefits offered: Social protection schemes can assist communities affected by extreme events associated with climate change and water scarcity by providing security/protection. Based on findings from this study, the development of a social protection system in Champhone district is still nascent. There are only two social protection schemes for government officers and a community-based healthcare insurance (CBHI) that is being piloted in a few villages of the district. There is no crop, livestock, asset, and agricultural product minimum price insurance in the district (Saykham et al. 2015). Projected climate change, particularly increased temperatures and rainfall, will increase the frequency and severity of environmental shocks, including floods, droughts, water scarcity, sharp temperature fluctuations, all affecting human health and livelihood assets (ibid.). Improvements in access to social protection schemes will assist communities in Champhone district to cope with extreme events.

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Notes

[1] This is different from the national poverty line. According to the national poverty threshold, only 27 households are identified as poor, representing 0.14 percent of the total population in the entire district.
[2] Interviews, Champhone District Office for Agriculture and Forestry and Champhone District Office for Health.
[3] Interview, representative of Champhone District Office for Agriculture and Forestry, 2016.
[4] Interview, representative of Champhone District of Agriculture and Forestry, 2016.
[5] Interview, representative of Champhone District of Agriculture and Forestry, 2016.
[6] Information sheet, Champhone District Office for Health.
[7] Interview, representative of Champhone District Office for Health, 2016.
[8] Interview, representative of Champhone District Office for Health, 2016.
[9] Interview, representative of Champhone District Office for Natural Resource and Environment, 2016.
[10] Interview, Champhone District Office for Public Works and Transport, 2016.
[11] Household survey, 2016.
[12] Household survey, 2016.
[13] Focus group discussion, 2016.
[14] Household survey, 2016.
[15] Household survey, 2016.

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10

Assessment of hydrology for agricultural development based on climate change impacts in Prek Thnot River Basin, Cambodia

Khem Sothea, Suy Sovann, Hun Sothy, Pory Sakhon and Uk Samseiha

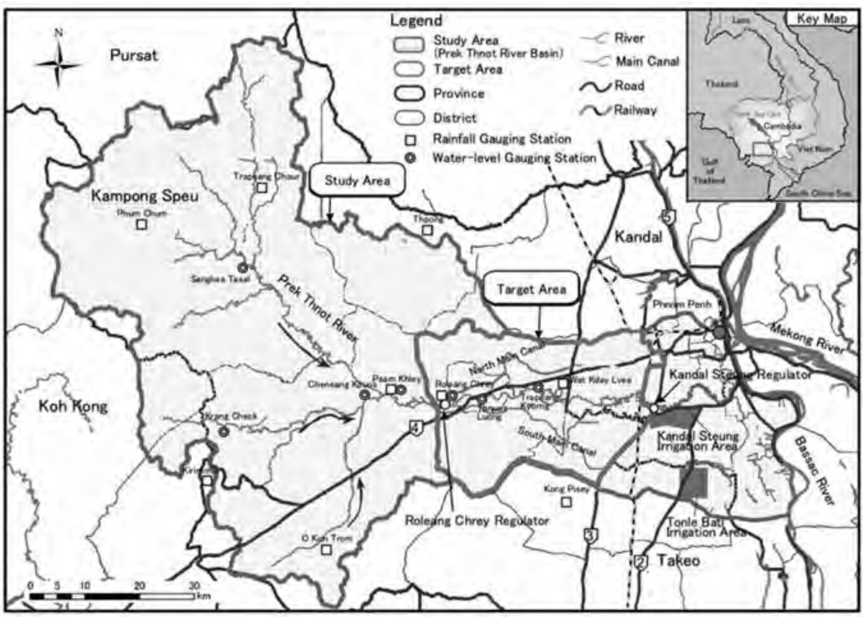
The longer-term consequences of climate change on precipitation patterns are uncertain and hold implications for the future of water resources and the viability of dry season rice cultivation in Cambodia. The impacts of climate change and the increasing demands on water for irrigation and other purposes need to be considered in formulating policy responses for water management. This chapter provides an assessment of the combined impacts of climate change, land-use changes, and upstream hydropower development on water resources during the dry season in the Prek Thnot River Basin, Cambodia. Agriculture, especially rice farming, in the Prek Thnot River Basin is vulnerable to drought because it relies on rainfall, with limited irrigation and water storage infrastructure.

The Prek Thnot River is one of the major tributaries of the Mekong River. The 232 km-long river flows east-southeast from its source in the Elephant Mountains and empties into the Bassac River. The Prek Thnot River Basin covers five provinces (Koh Kong, Kampong Speu, Kampot, Takeo, Kandal, and Phnom Penh), 18 districts, and 132 communes. The river's total catchment area is about 5,433 km^2 with the highest elevation at 1,543 m above mean sea level. Agriculture covers about 85 percent of the total basin area during the dry season. Agriculture is the main water use in the Prek Thnot River Basin, especially for rice farming during the dry season.

Traditional methods of bringing water to the ricefields from wells and small canals using manual labor are still prevalent in the Prek Thnot River catchment; as such, the area is still far behind the irrigated water systems elsewhere in Cambodia, especially areas located along the mainstream Mekong River (JICA 2012).

This study selected the Prek Thnot River Basin (fig. 10.1) in order to assess its hydrology for agricultural development due to the importance of agriculture in the basin combined with the need for improved water management. The basin is presently facing a number of critical challenges to its water supply, ranging from changes in climate and land use to upstream hydropower dam development. At the same time, there is inadequate hydro-meteorological data about the basin to make effective policy decisions for sustainable water resource management.

Figure 10.1. Project study area, Prek Thnot River Basin



Methodology

A hydrological model known as the Soil Water Assessment Tool (SWAT) was used,[1] following a Robust Decision Support (RDS) framework, to identify a set of potential adaptation strategies. The outputs were also intended to be a contribution to the Royal Government of Cambodia's policy on agricultural development in the Prek Thnot River Basin (MOWRAM 2012).

Uncertain conditions and adaptation strategies were identified using the XRLM framework (Lempert 2003) as part of the RDS methodology (Bresney and Escobar 2017) during a participatory problem-formulation workshop. Participating stakeholders were government officials and representatives of local water user groups. The information gathered during the workshop was the basis for the scenario analysis using the hydrological model (SWAT) (Shawul A. et al. 2013). SWAT results were integrated into a trade-off analysis using Tableau software with the decision space visualization process described in Forni et al. (2016).

Results

Using the XLRM framework

To evaluate strategies under uncertain conditions and to support ongoing strategic planning, the RDS method was used to provide theoretical decision-making under uncertain conditions based on the XLRM framework. The starting point for the XLRM framework is that traditional decision-making approaches based on an assessment of the likely probabilities of future conditions do not respond well to a situation such as climate change, where there is no consensus regarding the likelihood of specific climate futures.

XLRM framework is divided into four components:

- X (eXogenous factors) represents the uncertain factors outside the direct control of the actors within a particular decision-making process, but which have the potential to influence outcomes.
- L (Levers) represents the specific actions that are available to these actors as they seek to improve conditions or outcomes in the face of future uncertainty.
- R (Relationships) is the suite of analytical tools deployed to capture the exogenous factors and represent the levers identified by the actors, which when deployed produce estimates of ...
- M (Metrics of Performance), which are the means by which individual actors will evaluate the outcomes associated with a specific action considered as part of the decision-making process.

On October 19, 2015, the study team held its first national problem formulation workshop in Kompong Speu province, with participation from key central government ministries and local communities in Prek Thnot River Basin. This workshop introduced the concept of the XLRM framework focusing on water scarcity in the basin. This framework allowed for the identification of four components of XLRM (uncertainties, strategies, model, performance metrics) that contribute to the analysis of risks and the assessment of vulnerabilities and adaptation options.

These four components include exogenous factors or uncertainties (X), policy levers (L), relationships (R), and metrics of performance (M). The exogenous factors (X) are outside of decision-makers' control (e.g., the impacts of climate change on hydrology), but could impact the performance of the system. The strategies/policy levers (L), are the strategies or plans that decision-makers can adopt to reach their management objectives. For example, the construction of a reservoir. The relationship (R) relates to the analytical tools used to represent the interlinks between the uncertainties and strategies (X and L).

The participants were divided into two groups: group I, comprised of local communities/grassroots level participants; and group II, comprised of policy level officials from the ministries and provincial departments. Drawing on the experiences of officials (group II) and local communities (group I), the workshop centered on the question of "How could we facilitate a link between uncertainty factors to policy actions?" Based on this workshop, the main concerns in the area were identified as water resources availability and changes in the flows, or hydrological regime, of the river; climate change; changes in land use; and the impacts of upstream hydropower development on the basin's hydrology.

Results from application of RDS

Table 10.1 shows the scenarios identified based on the output from the problem formulation workshop. These scenarios were simulated using the SWAT modeling tool.

Table 10.1. Uncertain factors (X) and strategies/levers (L)

XLM Matrix	Description
X1 Climate Scenarios	Baseline 1985–2011, Future projection 2012–70
a) Dry climate b) Wet climate c) Average/Normal climate	Applying different conditions of Climate Scenarios based on Dry, Wet and Normal conditions
X2 Deforestation Scenarios	
a) High rate of deforestation (100%)	All (100%) deciduous forest changed to agricultural land (85%) and urban area (15%)
b) Medium rate of deforestation (50%)	Deciduous forest changed to Agricultural land (40%) and urban area (10%)
c) Low rate of deforestation (20%)	Deciduous forest changed to Agricultural land (15%) and urban area (5%)
Strategies/Levers (L)	
L1 No strategies	No strategies are implemented
L2 Large infrastructure development	Dam/reservoir in sub-basin 3, beginning in 2020 (mainly for hydropower and some dry season irrigation)
L3 National plan (Expansion irrigation areas)	Expansion of agricultural land
L4 Combination of L2+L3	

Note: Dry, wet and average climate resemble the climate projections which have the lowest dry season rainfall, highest wet season rainfall, and average rainfalls during the projected period (2011–90), respectively, compared with the observed historical average.

Using model-based analysis

Data collection

Hydro-meteorological data, such as rainfall, pan-evaporation, water levels and flows from different stations in the study area during the same time period, were collected and combined with field investigations.

The measurement of water levels in the study area is paramount for both validation and calibration of the models and for the monitoring of future changes. The hydrological data, i.e. daily rainfall, river flow, and climate data, were collected from the Ministry of Water Resource Department of Hydrology and River Works (DHWR) and the Department of Water Resources and Meteorology in Phnom Penh from 1985 to 2011. The average rainfall in each sub-catchment was calculated based on the Thiessen polygons method. Additional spatial data such Digital Elevation Model (DEM-50), Land use (for 2003, 2010), Soil type (2002) and GIS data were collected from studies done for the Mekong River Commission Secretariat. From the population statistics in 2014, gender data and a topographical map were collected for the provincial level from the Department of Water Resources and Meteorology in Kampong Speu.

The climate data used as an input to SWAT were downscaled predictors from the Regional Climate Models (RCM) with the spatial resolution of 0.44° (50 x 50 km). This climate data was corrected using the Linear Scaling Method. For this study, three climate scenarios were proposed: dry, wet and normal. The dry climate resembled the climate projection, which has the least dry season rainfall during the projected period (2011–90) compared with the observed historical average, while the wet climate resembled the climate projection, which has the highest amount of wet season rainfall during the projected period. Normal climate projection data was identified by finding the climate projection which resembles closest to the observed historical data.

The SWAT model

SWAT (developed by the United States Department of Agriculture's Agricultural Research Service), was used to evaluate the impact of future climate change, combined with data on land-use changes and hydropower dam development upstream of the Prek Thnot River Basin. ArcGIS 10.1 based on the digital elevation model (DEM:50x50) was used to generate the stream network of the watershed and to identify the outlet points for a given threshold value.

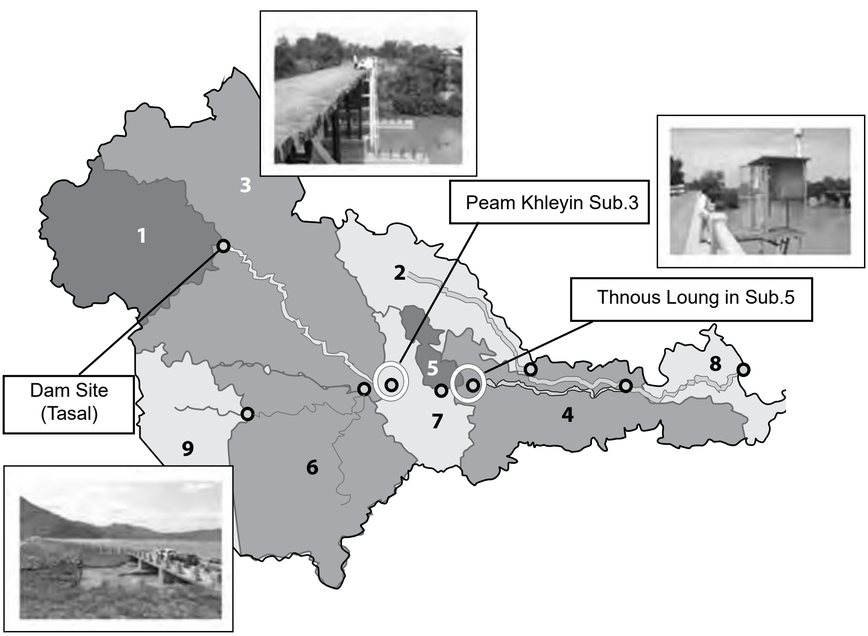
The main watershed was automatically delineated into nine sub-catchments using SWAT, as illustrated in fig. 10.2. The land phase of the hydrological cycle is described by the transient water balance equation applied to water movement through the soil, namely:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{\square} - Q_{\square} - ET_{\square} - P - QR)_{\square} \quad (1)$$

Where,
SW_t, Final soil water content after t days (mm water),
SW_0, Initial soil water content (mm water),
R, Amount of precipitation on day i (mm water),
Q, Amount of surface runoff on day i (mm water),
ET, Evapotranspiration on day i (mm water),
P, Amount of percolation and bypass flow exiting the soil profile bottom on day
QR, Amount of Groundwater flow on day i (mm water); i (mm water), and t, time (days).

For evaluating model performance of the goodness-to-fit between the calculated and observed discharge, the Nash–Sutcliffe coefficient of efficiency (COE) was used.

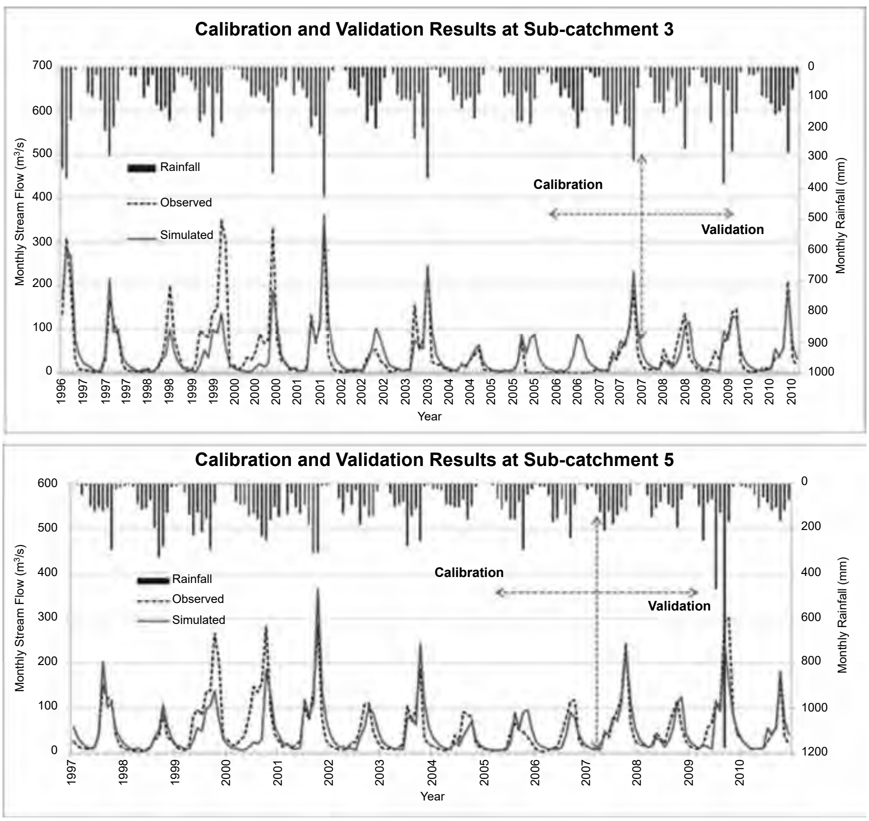
Figure 10.2. The delineated sub-catchment used in the SWAT model in the Prek Thnot River Basin



Baseline results from SWAT

Model calibration was done for the years 1996 to 2007 through the trial-and-error approach, and the data for 2008 to 2011 were used for model validation. Model runs were done using daily, monthly and yearly time-steps. Based on the watershed topographical feather, the Prek Thnot River Basin is divided into nine sub-catchments. Since sub-catchment 3 and 5 represented the outlet of inflow for the entire river basin, sub-catchment 3 and sub-catchment 5 were selected for model calibration and validation (fig. 10.3).

Figure 10.3. Simulated baseline flows from 1996 to 2011 at sub-catchments 3 and 5



SWAT-simulations of climate change impact

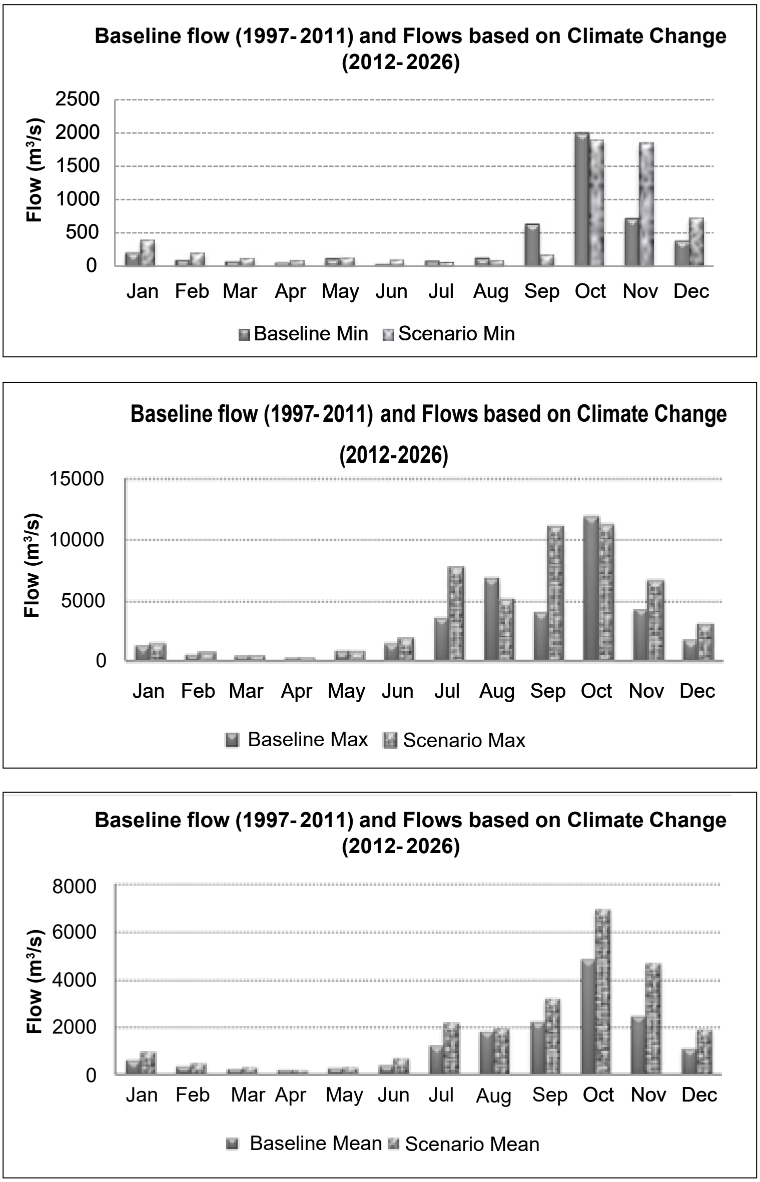
Latest research suggests that a global increase in temperature exceeding 2.0°C is inevitable and most likely to occur by mid-century (Cho et al. 2015). Temperature increases on the upper end of the IPCC's projections (4°C) are likely in the absence of rapid and dramatic changes in global energy policy (Cho et al. 2015). The implications of these changes for the Mekong Region are that the people and much of the public infrastructure that currently exists, or is being planned, will be directly exposed to the impacts of climate change.

To quantify those impacts in the future and in regards to water resources availability in the Prek Thnot River Basin, Regional Climate Models (RCM) data were retrieved and analyzed. Long-term variations in monthly flows from sub-catchment 3 (Peam Kley Station), focusing on the dry season based on climate change scenarios from 2012 to 2026 and referring to the maximum, minimum and average conditions, were compared to the baseline monthly flow (1997–2011) are shown in fig. 10.4.

It was found that climate change will cause a reduction in the Prek Thnot River's flow during the dry season with a shift in the early wet season from March to July, which can exacerbate drought conditions and delay the rainy season, while also causing more intense rainfall and greater flooding during the wet season during August to October. The study model suggests that maximum flows are going to increase significantly from the years 2012 to 2026 in comparison with the baseline. The frequency and magnitude of flow increases during the wet season, and consequent flood inundation, could damage infrastructure and crops.

The model shows an increase in annual average streamflow of 50 percent based on one of the climate projections, during the wet season. In the dry season, flows significantly decreased by 50 percent based on one of the projections of climate change. Therefore, the required adaptation strategies need to take into account seasonal variability. With regards to changes in the average flow, the future values under the climate change projection (JICA 2012) show a decrease in the dry months (March to May) and early wet season (June to July), but it shows higher flow values in August and September. This would lead to irrigation water shortages for dry season crops and would also affect the early growth stages of wet season crops. Adaptation measures, such as adjusting crop calendars and patterns, as well as efforts to manage water surpluses during the flood season, should be considered.

Figure 10.4. Variations in monthly flow at sub-catchment 3 (Peam Kley Station) due to climate change scenario (2012 to 2026) compared to the baseline monthly flow (1997–2011) under maximum, minimum and average conditions



Vulnerability analysis for drought management

The vulnerability analysis sought to answer the following questions: How do the selected projects perform under our chosen suite of uncertain futures? What are the trade-offs amongst different water management strategies in the face of all identified uncertainties?

Robust strategies are those that perform consistently well under the most number of uncertainties, based on the measures of success identified. The vulnerabilities of the Prek Thnot Basin under current water management and under the variety of uncertainties defined through the RDS framework were assessed by the SWAT model. The performance of the system was evaluated with the identified performance metrics (M) from the XLRM framework. Water demand across sectors (agriculture, industry, energy, urban, environment) is affected by climate variability, land-use changes in the region and contractual issues amongst many water communities in the Prek Thnot River Basin. These factors are difficult to integrate because social, political, and economic boundaries often overlap with watershed boundaries and other physical delineations critical to water resources systems.

The procedure used to develop a vulnerability mapping based on the performance metrics mentioned above are described in three interrelated phases:

- the time series output of flows from SWAT and performance thresholds in each sub-catchment;
- the representation of relative vulnerabilities in an aggregated graphics based on future projections; and
- the visualization of the "vulnerability map" that represents the degree of the impacts

Results from the SWAT model include different scenarios of climate change, land-use changes and upstream hydropower development that were used in a trade-off analysis constructed using Tableau. This system-level vulnerability has significant effects on the water availability for upstream and downstream demand sites, including rural and agricultural users who rely exclusively on a reservoir. The threshold for environmental flow at sub-basin 3 and 5 were selected based on the 90th percentile of river discharge.

Similarly, for water availability in the Prek Thnot River during the dry season which is necessary for river navigation, the minimum water level of 1.5 m was selected as a threshold based on the consultation meeting with stakeholders. The simulated river discharge from the SWAT model was converted to the water level using the available rating curve at the outlet of sub-catchments 3 and 5. And finally, for assessing the vulnerability of reservoir to different uncertainties and strategies, the threshold of 40 MCM (million cubic meters) was selected.

The Tableau software is used to produce interactive data visualizations that fill a crucial communications gap and enable stakeholders and decision-makers to analyze all the impacts for better planning. The threshold and acceptable levels for the performance metrics used in the vulnerability map are shown in table 10.2.

Table 10.2. Threshold for matrix of performance for Tableau program

Metrics of performance	Description	Threshold Value	Acceptance Level (AL) % times the system is allowed to underperform
River flow	Minimum discharge required for environment	6.5 m^3/s at sub-basin 3 and 9.4 m^3/s at sub-basin 5	25%
Water level for transport	Minimum water level required for river navigation. Water level is calculated based on discharge and rating curve.	1.4 m at sub-basin 3 and 1.5 at sub-basin 5	40%
Water volume in the reservoir	Minimum volume of water required in the reservoir for hydropower and irrigation.	40 MCM	50%

Environmental flows

Environmental flows are the seasonally and annually varying water flows and levels that support ecosystems and human livelihoods while providing for other uses such as hydropower, irrigation, and water supply. Many governments and river management agencies around the world have developed policies to protect environmental flows, and more are doing so all the time. Yet, implementation of these policies remains weak. Policies to limit water abstraction and flow alteration are needed, as it is much easier to impose requirements on new users than to enact changes to existing water use. It is better to introduce a cap now that can be relaxed later if warranted, than to allow water use to impair ecosystems, resulting in the need for difficult future reallocation processes.

Figure 10.5 (see Appendix) shows a Tableau dashboard for the Failure Matrix for environment flows that illustrates the results for the environmental flow in Prek Thnot sub-catchments 3 and 5. It shows that there is a strong effect on the environmental flow in the downstream sub-catchment 5 in the presence of the combined factors of hydropower development upstream (L2) and the combination of a hydropower plan and expansion of irrigation areas (L4 basin). Given that the acceptance level for environmental flows is 25 percent, the vulnerability of the strategy that is above 25 percent is indicated in red, whereas those below 25 percent is indicated in green. It was also found that strategies L2 and L4 were most likely to impact the environmental flow in sub-catchment 5.

Water for transportation

Today, the Prek Thnot River is still an essential means of transportation for many of the people living in the river basin and plays an increasingly important role in the upstream and downstream trade, fisheries and of course, tourism. The Prek Thnot River is a major tributary that is navigable during the high-water period. Based on the trade-off analysis, it was found that there is no impact on the water level in the upstream area, but there is a strong impact downstream. Under an acceptance level of 34 percent, all strategies including L1 were not significantly impacted in sub-catchment 3. However, for sub-basin 5 under L2 and L4 strategies, the vulnerability is higher than 51 percent. This implies that for 50 percent of the time, the river might not be navigable downstream, and this occurs under all the climate projections if upstream dams continue to be built and the expansion of irrigation area is taken into account. Figure 10.6 (see Appendix) presents the Failure Matrix for water levels in the selected sub-basins 3 and 5. A significant increase in vulnerability values is found for L2 and L4. This figure shows the strong impact for downstream navigation, if hydropower dam and irrigation expansion are considered.

Reservoir volume for hydropower

In accordance with engineering standards, reservoirs are to be designed to provide stability and durability, as well as to protect the quality of the stored water. For any particular project, there may be more than one acceptable reservoir design concept. The reservoir design criteria are not intended to establish any particular design approach, but rather to ensure water system adequacy, water supply reliability, and compatibility with existing and future facilities.

The Failure Matrix for water volume in the reservoir is presented in fig. 10.7. It is noted that water shortages occur in the dry season with more than 50 percent of reliability when combined with land-use change from forestry to agriculture (high, medium, low).

It also was observed that reservoir volumes are most likely to fall below the limiting value of 40 MCM mainly during the dry season. Under projected dry climate, the reservoir volumes will have an impact on water use throughout the Prek Thnot River Basin. This can have a significant impact on the ability to generate hydropower by releasing water from the reservoir or storing water in the reservoir for dry season irrigation.

Figure 10.7. The Failure Matrix for water volume in the reservoir

Land Use Change	Climate Change	Strategy L2
1. Highest Rate of Deforestation	Avg. Climate	48%
	Dry Climate	52%
	Wet Climate	41%
2. Medium Rate of Deforestation	Avg. Climate	48%
	Dry Climate	52%
	Wet Climate	41%
3. Low Rate of Deforestation	Avg. Climate	48%
	Dry Climate	52%
	Wet Climate	41%

Water shortages in very dry years are expected to occur more frequently. The worst shortages could occur under one of the climate change projections, where downstream flow would be significantly reduced or curtailed during March to July or from July to August (the start of wet season cropping and productive period). A disruption to the water supply in this period could reduce crop yields and increase the risk of crop failure. Adaptation measures should be put in place, including mainstreaming of climate resilience in drainage and storage capacity design based on predicted flow and water level change, flood management measures and investment in proper maintenance of existing irrigation systems; however, these measures have so far been largely neglected in policy.

Discussion and conclusion

The RDS methodology using a SWAT Model and XLRM framework analyzed the impact of water availability in the Prek Thnot River Basin based on distinct climate change, land-use change, and upstream infrastructure development. The results of the SWAT model are considered to have reasonable outcomes and to have the capacity to properly represent the watershed. The results were shown in Tableau for the vulnerability analysis of each involved factor in reference to environmental flows, water levels for transportation and water volumes for reservoir.

Since the project assessed the performance of different strategies for different performance matric under various situations, the findings from this project could be used as a basic framework for the development partners (MOWRAM, MAFF and MoE) and other stakeholders in the Prek Thnot River Basin to improve dry season water management in consideration of future climate change, land-use changes and large infrastructure development in the upstream areas.

The study found that the worst water shortages would occur under the climate change scenario where downstream flow would be significantly reduced or curtailed during March to July or July to August (the start of wet season cropping and productive period). A disruption to water supply in this period could reduce crop yields and increase the risk of crop failure.

The concept and approach used in this project could be applied to help improve the existing National Adaptation Plan and other plans in the future taking into account climate uncertainties, land-use change and other factors. The decision-makers at all levels (provincial, community) need to address medium and long-term adaptation needs with an effective adaptation plan and process. The results of this study will help decision-makers propose new adaptation strategies for agricultural development and water resource management at the provincial level.

In conclusion, the RDS methodology could be used to support the formulation or improvement of adaptation planning process of the basin in the following ways:

- Identify the level of climate risk for different water users under different situations;
- Integrate relevant adaptation strategies from different agencies into a joint planning process;
- Help prioritize the adaptation strategies for future investment based on the results of their performances under different situations;
- Incorporate different factors of uncertainties into the decision-making process related to infrastructure development;
- Enhance the confidence of relevant agencies to support local communities (including water user groups) to engage in the planning process through continued dialogues based on a joint assessment plan and performance assessment results; and,
- Contribute to iterative learning on how to manage multiple stress factors that are occurring across the Prek Thnot region.

Acknowledgments

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11

Chindwin River Basin: Water scarcity amidst plenty

Thanapon Piman, Jayaram Pudashine, Chusit Apirumanekul, Chayanis Krittasudthacheewa and Somsanith Mounphoxay

Global warming has caused extreme changes to the quality, quantity and availability of water resources, particularly in the monsoon region of Asia (IPCC 2014). The frequency and intensity of hydrological, meteorological and climate disasters have been increasing over the last 50 years (IPCC 2012). The Mekong Region is affected by the El Niño and La Niña phenomena that often alters the seasonal monsoon cycle and causes wide-ranging changes in weather patterns (ASEAN 2017). The region also experiences, with increasing frequency and magnitude, floods and droughts that alter river flow regimes and sediment deposits, and cause the loss of wetlands and floodplains, and salinity intrusion in river deltas due to sea level rise (Arias et al. 2013; Oeurng et al. 2016; Dang et al. 2017). Climate change also poses major threats to agriculture, fisheries, and forest ecosystems which are sensitive to variations in temperature, rainfall, and flow regimes (Mainuddin M. et al. 2010; ASEAN 2017; Sabo et al. 2017; Trisurat Y. et al. 2017).

Myanmar is highly vulnerable to the negative effects of a changing climate and extreme events. The observed evidence of change over the last 60 years in Myanmar includes a nationwide increase in temperature at an average rate of 0.08°C per decade, changes in the duration of the monsoon season, an increase in the occurrence of floods and droughts, and a rise in sea level (UNEP 2012). Water resources are expected to be significantly affected by climate change, since changes in temperature and rainfall patterns will add a level of uncertainty to water availability, as well as lead to an increase in the frequency and magnitude of extreme flood and drought events.

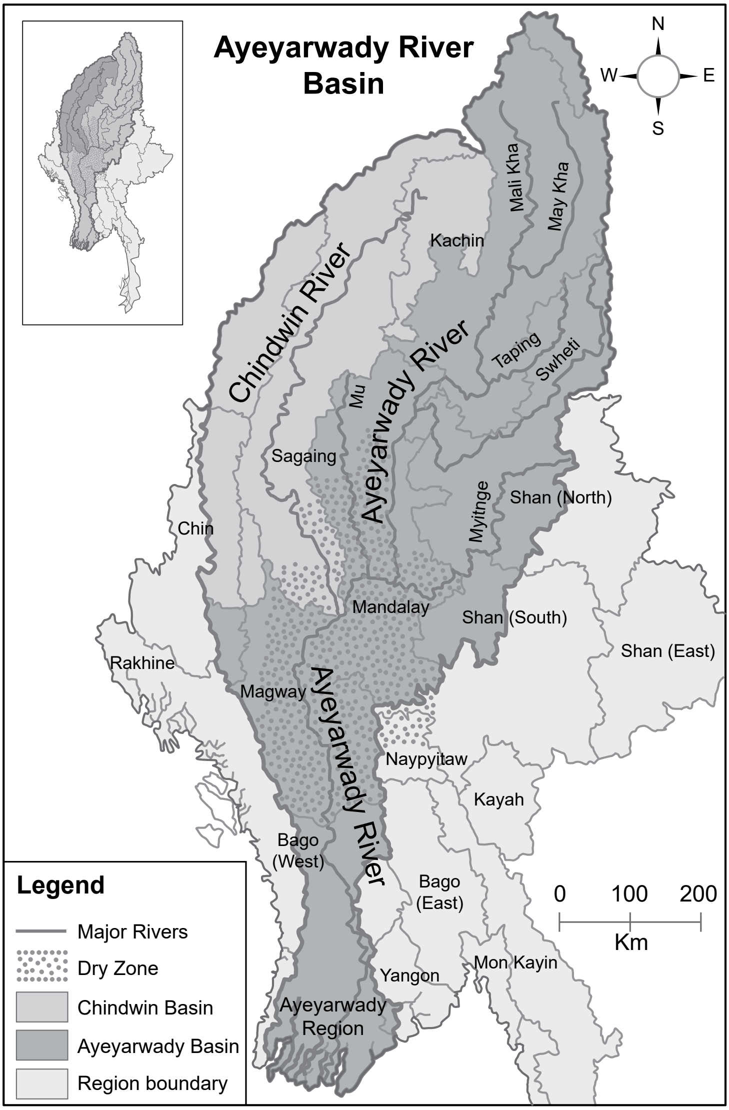
The Chindwin River is the largest tributary of the Ayeyarwady River in Myanmar. The health of the river is critical for sustaining the livelihoods of six million people, facilitating the economic development of the region, and providing ecosystem services. An extreme drought event in 2010 caused the depths of the Chindwin River during the dry season to drop to levels much lower than those seen in the past, making it difficult for boats to travel upstream (Tin et al. 2014). The low water levels affect agricultural activities due to insufficient water supply, as well as the local economy, which depends heavily on river transportation for the trade of goods such as rice, cooking oil, dried fish and fish paste with other parts of Myanmar (May et al. 2015). During the wet season, the Chindwin River also faces challenges from extreme floods. Losses to life and the economy from the most recent floods in Myanmar in 2015 were the highest ever in the Chindwin Basin (OCHA 2016).

Compounding these extreme events, water resources in the Chindwin River Basin are under pressure from economic development that include mining, cash crop expansion, logging and navigation, resulting in land-use change, deforestation, increased water demands and environmental degradation, with consequent impacts on people's livelihoods (May et al. 2015). Securing water for different needs has therefore become a complex issue and represents a critical challenge for water resources management in the Chindwin River Basin. The Myanmar National Water Policy of 2014 mentions several concerns related to water security and the challenges for water resource management in order to support rapid growth in water demand, urbanization, industrial and economic development, as well as to adapt to climate change impacts, particularly extreme floods and droughts. The national policy emphasizes the importance of research and the use of decision-support systems to support sustainable water resources management.

However, there is a lack of an integrated basin study to assess development strategies across water-related sectors while taking into consideration uncertainties in climate, landscape and socioeconomic conditions. This chapter documents the application of a Robust Decision Support (RDS) framework to address water security issues in the Chindwin River Basin. A multi-stakeholder participatory approach was used to explore the uncertain impacts of climate change, land-use changes and population growth on key aspects of water security. The specific aim was to help assist policymakers from different agencies and other stakeholders in Myanmar to identify robust strategies to address drought under highly uncertain conditions.

Study area

Figure 11.1. Ayeyarwady and Chindwin River Basins



The Chindwin, the largest tributary of the Ayeyarwady, is the third largest river in Myanmar (fig 11.1). It has a drainage area of 114,112 km^2 comprising of 86 percent forested area and 14 percent agriculture, mining, village and shrub lands; 15 percent of the basin lies within India, hence the basin can be classified as transboundary. The Chindwin River rises in the Kachin Plateau, which has the second highest mountain in Myanmar. Its main geological features are sandstones of different hardness, clay with gypseous veins, shale and limestone. The length of the Chindwin River from its headwaters to the Ayeyarwady confluence is approximately 1,200 km. This basin spans over 46 townships in four regions in Myanmar, namely Sagaing, Kachin, Chin and Magway. The basin is home to a total of 6 million people: 2.5 million in the Indian part and 3.5 million in the Myanmar part (Gaughan et al. 2013; World Bank 2015). About 90 percent of the six million people living in the basin are heavily dependent on a healthy river and rely on it for drinking, agriculture and livestock, fisheries and navigation.

The rainfall over the basin is an important source of water supply in the Chindwin River Basin. The heaviest rain falls during the strong monsoonal depression that occurs across the basin from May until October. The dry season stretches from November to April. The average rainfall in the catchment area varies from 1,500 mm to 4,200 mm. The Myittha, Yuwa and Uyu Rivers are the three major tributaries of the Chindwin River. Monthly average temperatures vary between 23^0C in the upper basin to 28^0C in the lower basin near Monywa. The annual average flow of the Chindwin River is 4,500 m^3/s, which is about 40 percent of the annual average flow of the Ayeyarwady River. The average dry season flow is about 15–20 percent of the annual average flow. The average annual sediment load in the Chindwin River Basin is 109 Mt, which is 42 percent of the total sediment load of the Ayeyarwady River Basin (ICEM and MIID 2017).

Methodology

The Robust Decision Support (RDS) applies a participatory framework to integrate the natural, social, and political aspects of water resource management in a quantitative model for Integrated Water Resource Management (IWRM). RDS is increasingly being used to support long-term water planning (Grove et al. 2012; Mehta et al. 2014; Bresney and Escobar 2017). This case study used the RDS framework and a sophisticated simulation model to evaluate drought management strategies across a number of plausible future climate scenarios, demographic growth, and land-use change, as well as to employ statistical analysis to identify vulnerabilities and robustness of drought management strategies. Following the RDS framework, the following steps were used to conduct this case study.

1 Policy review on water scarcity and drought management

A literature review was conducted to build a common understanding on water scarcity and drought management issues in Myanmar. The policy review focused on an in-depth assessment of existing water scarcity and drought management approaches related to laws, policies, strategies and plans as well as relevant management institutions in order to: i) understand the purpose and goals of the policies; ii) identify policy gaps; and iii) identify key policies and strategies to be assessed in the case study. Information on policies relevant to disaster management, water resources management, agriculture, forestry and climate change were collected from key government agencies, including the Inter-Ministerial Cooperation for Disaster Management, Ministry of Transport, Ministry of Agriculture and Irrigation, Ministry of Environmental Conservation, Ministry of Social Welfare, Relief and Resettlement, and Ministry of Health.

2 Problem formulation through stakeholder consultation

A problem formulation framework, XLRM, provides a useful tool to identify four decision components, including exogenous factors or uncertainties (X), policy levers (L), relationships (R), and metrics of performance (M). The exogenous factors (X) are outside of decision-makers' control, e.g., the impacts of climate change on the hydrology, but could impact the performance of the system. The policy levers (L), are the strategies or plans that decision-makers can adopt to reach their objectives, e.g., the construction of a reservoir. Relationship (R) relates to the analytical tools used to represent the interlinks between the uncertainties and strategies (X and L).

To take one example, in a water resources planning simulation model such as the Water Evaluation and Planning (WEAP) model, the performance metrics (M) are the management outcomes that allow the evaluation of the success or failure of decision-makers' potential policy options. For this study, the results from the policy review in the first step were used to facilitate the discussion on problem formulation among the stakeholders. The outputs from the XLRM framework were used to formulate scenarios and identify the key issues, strategies, and measures for the assessment.

Figure 11.2. Stakeholder consultation meeting on October 6, 2015 on problem formulation for the Chindwin River Basin

A series of discussions and stakeholder consultation meetings were organized to introduce the RDS framework and collect stakeholder's concerns about the impacts of key drivers, i.e. climate change, population growth and economic development, on water resources management and drought management in the Chindwin River Basin (fig. 11.2). The key stakeholders in this study were: government agencies from the central government and the regional Sagaing government, such as the Directorate of Water Resources and Improving River System, Irrigation

Department, Department of Meteorology and Hydrology, Water Resources Utilization Department and Forestry Department; academic institutes, including Monywa University, Mandalay University and Sagaing University of Education; local communities; and local and international nongovernmental organizations (NGOs).

3 Model setup and large ensemble model runs

The WEAP model was selected as a tool to assess the impacts of climate and non-climate uncertainties on water allocation in the Chindwin River Basin. In addition, WEAP model was selected because of its capacity to simulate scenarios and because it had already been used for this basin in other studies. It was also used to evaluate the robustness of selected drought management strategies. The WEAP model is a Windows-based decision-support system for IWRM and policy analysis (http://www.weap21.org). The WEAP modeling platform allows the integration of pertinent demand and supply-based information together with hydrologic simulation capabilities in order to facilitate analysis of a range of user-defined issues and uncertainties, including those related to climate, watershed conditions, anticipated demand, ecosystem needs, land-use change, regulatory drivers, operational objectives, and infrastructure (Yates et al. 2005a)

Input data for WEAP

The WEAP model requires data related to hydro-meteorology, land-use, demographic information and water-use for different sectors. These input data used in the running of the WEAP model are presented in table 11.1. Selected data were collected from the Department of Meteorology and Hydrology (DMH), Myanmar Information Management Unit (MIMU), while some data was obtained from global data sources.

The climate projections data was obtained from the Regional Climate Models (RCM) and corrected using the Linear Scaling Method, which adjusts the arithmetic mean and the standard deviation (Teutschbein and Seibert 2012).

Model setup

Figure 11.3. Schematic of the WEAP model for the Chindwin River Basin and discharge stations for model calibration

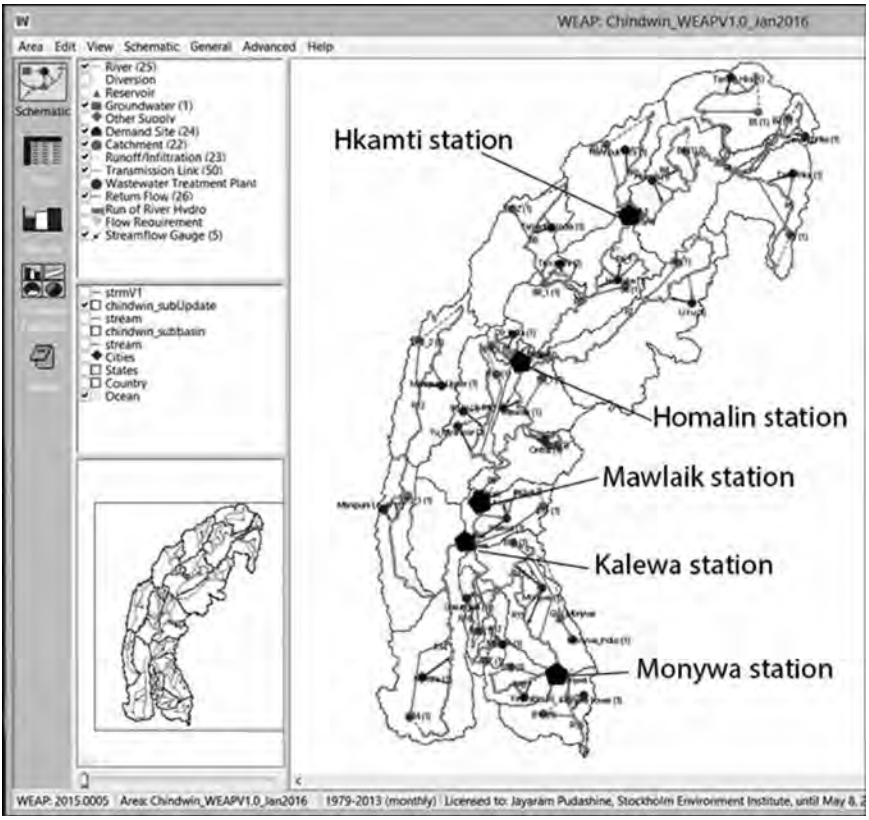


Table 11.1. Input data for the WEAP model

No.	Data Type	Frequency	Sources
1 2 3 4 5	Rainfall Temperature Wind Speed Relative Humidity Cloudiness Cover	Monthly	Department of Meteorology Hydrology and National Center for Environment Prediction(NCEP)/Climate Forest System Reanalysis (CFSR)
6	Discharge	Monthly	Department of Meteorology Hydrology
7	Population	Annual	Myanmar Information Management Unit and UN database
8	Water Use	Annual	AQUASTAT
9	Land Use	-	Global Land Cover by National Mapping organization (GLCNMO) http://www.iscgm.org/gm/glcnmo.html
10	Future Climate Data	Monthly	CORDEX East Asia and South Asia

The WEAP graphical user interface platform was used to construct a schematic map of the basin network and its hydrological attributes as shown in fig. 11.3. A total of 22 sub-basins were created based on the map from the Forest Department of Myanmar (Aye 2004). This map includes the main river network. The position and delineation of these elements were aided by GIS-derived graphic displays of the river network, sub-basin boundaries and the location of streamflow gauges uploaded to the WEAP application. Within these catchment nodes, climate data forces the simulation of runoff, infiltration, changes in soil moisture and evapotranspiration demand for a land cover composition via an empirically lumped parameter function that operates in a layer box soil accounting scheme (Yates et al. 2005b).

Model calibration

Five discharge gauges located along the river basin (fig. 11.3) were used to calibrate the simulated streamflow across the Chindwin River from 1979 to 2000. This period was selected to exploit the overlapping availability of continuous recorded climate and streamflow dataset. The WEAP model was simulated on a monthly time scale.

Scenario development and large ensemble runs

A number of scenarios were defined based on key uncertainties (X) and policy levers/strategies (L) according to problem formulation and the XRLM framework as described above. Details on the XLRM result and scenario formulation are presented in the results section. Large ensemble runs included all possible combinations of scenarios, including climatic and other uncertainties and policy levers. There were 36 combinations of uncertainties, including three climate change scenarios, three land-use change scenarios and four population change scenarios. When these uncertainties were combined with four policy strategies, a total of 108 ensembles were developed. All these ensembles were programmed to run in Python Programming software for complex scientific applications using visualization through the WEAP API interface.

The baseline/reference period was selected from 1985 to 2014 (30 years) and future scenarios were set to be 2015–2074, which was split into two periods of 30 years each: the years 2015–2044 as a Near Future, and the years 2045–2074 as a Far Future.

4 Scenario exploration and visualization

Each strategy was tested under all combinations of uncertainties to determine whether they performed satisfactorily or not. This test is achieved by introducing the threshold value or level of satisfaction. The vulnerability map is prepared based on all these above thresholds by using Tableau 10.1 (Sood et al. 2013) to visualize and perform the data analysis, which provides a robust framework for handling large datasets and creates a simple visualization output which is easy for decision-makers to understand and interpret technical results. Model outputs correspond to stakeholder-determined performance metrics (M) from the XLRM framework. Stakeholders can explore and interact with the visualization in three progressive steps, which transform the model output to meaningful information. Forni et al. (2016) shows three steps for Decision Space Visualizations that account for knowledge exchange and help construct a shared mental model of a region's water resources system, including its current state, future challenges, and opportunities.

Results and discussion

Policy review on drought management

Numerous pieces of legislation and policy are related to drought and water scarcity management as summarized in table 11.2. In Myanmar, drought is not considered a major national issue compared to other natural disasters such as tropical storms, floods, cyclones, tsunamis and earthquakes. Droughts are less visible and do not receive the policy attention they deserve. Moreover, the phenomenon of droughts is such that their onset is gradual and hence only become evident during a "crisis." In contrast, floods or cyclones display their destructive power as soon as they strike. However, droughts can be as destructive as cyclones to different groups of people. An awareness of droughts and their destructiveness, as well as appropriate policy responses, is needed and warrants serious and long-term attention.

The central part of Myanmar is classified as an arid to semi-arid zone (dry zone) and is considered the most vulnerable part of the country (RRD 2012). The lower part of the Chindwin River Basin is in this dry zone area. DMH established the drought monitoring center for upper Myanmar at the Mandalay office in 2010 to prepare for the seasonal and annual drought reports based on rainfall conditions. Myanmar has established the Dry Zone Greening Department under the Ministry of Environmental Conservation and Forestry to work collaboratively with the Forest Department to convert the dry zone into a lush and green landscape and reduce the water scarcity in the region by conserving forest, soil and water resources (Whittle 2017). Previous responses to drought and water scarcity have been linked to water projects at specific locations. The responses usually include building ponds, check dams and tube wells to improve water supply in the dry areas of the country.

Agricultural development policies call for an increase in production (Than et al. 2015). As a result, more groundwater pumps and tube wells are currently being installed, to mitigate the problem associated with water scarcity for crop production. In the dry zone, a total of 33,081 tube wells have been installed to irrigate farmland. Groundwater extraction in Myanmar is growing at 2.9 percent annually (Vaughan and Levine 2015). However, the overuse of groundwater for agriculture may worsen the impact of droughts and lead to water scarcity.

Table 11.2. Summary of laws, policies, and plans related to water scarcity and drought management in Myanmar

Issue	Law and Act	Policy/ Strategy	Plan	Remarks
Disaster management	Natural Disaster Management Law (2013) National Disaster Preparedness Standing Order (2009, 2011)		Myanmar Action Plan on Disaster Risk Reduction (MAPDRR) 2009-2015 (2009) Myanmar Action Plan on Disaster Risk Reduction (MAPDRR) (2012)	In terms of nation-wide disaster management, drought is seen as less important compared to other disasters such as tropical storms, floods, tsunamis, and earthquakes. Drought is seen as a localized issue and as such addressed locally in projects tied to specific locations.
Water resources	Conservation of Water Resources and River Law (2006) Water Law/Water Act (2015)	National Water Vision (2004) National Water Policy (2014)	National Water Framework Directive (2015)	The 2014 national water policy provides comprehensive guidance for a holistic approach to water resource management. Additional legal frameworks, water framework directive and water law are currently being drafted. Establishment of river basin organizations (RBO) is expected to be promoted through these frameworks.
Agriculture	Vacant, Fallow and Virgin Lands Management Law (2012) Farmland Law (2012)	Strategy and Policies for Myanmar's Agriculture Sector (2013)		These policies and laws say little about drought. Myanmar's goal of maximizing the use of land as a natural resource to generate income is leading to increased agricultural productivity, expanded areas under irrigation and higher investment in agro-based industries. However, intensification of agricultural activities deteriorates soil quality and has led to increasing water use (including groundwater), both of which can reduce drought resilience or exacerbate effects of drought.
Forestry	Forestry Law 1992	Forest Policy (1995)		Promotes the sustainable management of forest resources. To date Myanmar has managed to avoid huge forest loss. However, the quality of forest has declined due to unsustainable tree felling practices.
Climate change adaptation		Draft National Climate Change Policy, Strategy and Action (2012)	National Adaptation Program of Action (2012) Initial National Communication under the United Nations Framework Convention on Climate Change (2012)	Climate change related adaptation and mitigation activities have gained momentum in the past few years. Many of these activities assist communities cope better with climate change. However, there is a need for further institutional development and capacity building, as well as an expansion and continuity of these activities for effective and lasting outcomes.

The National Water Policy of Myanmar (2014) signifies an integrated water resource management (IWRM) approach that addresses a wide range of issues, namely fair water allocation, adaptation to climate change, water-use efficiency, conservation, and the management of drought and extreme-weather events. For example, Article 2.5 of the policy asserts that the impacts of climate change on water resources availability must be factored into water management-related decisions and water-use activities must be regulated while taking into account the local geo-climatic and hydrological situation. Under this policy, water scarcity and drought will be integrated into river basin management plans, where a basin is treated as a unit with unifying perspectives and managed by inter-state/region agencies. There is a need to integrate measures to address water scarcity and drought into policies in all sectors so that the country's development can take place without placing an unfair burden on poor rural communities, especially those that mainly rely on subsistence livelihoods.

Myanmar is still rich in natural resources and the country has recently been open to international cooperation, as well as to new approaches for natural resources management, this being evidenced through the adoption of IWRM for its water policy. This provides an opportunity for the country to improve its existing policies and legal frameworks and address both institutional and operational difficulties associated with effective drought management and water scarcity. Coordination among different agencies is required for coherent planning and policy at national and basin levels, however. The RDS as the participatory planning tool is, thus, useful for this case study in the Chindwin River Basin to conduct integrated assessment and increase coordination between key stakeholders to address drought issues in the basin.

Problem formulation using XLRM

In October 2015, a stakeholder consultation was organized to discuss and identify key concerns, uncertainties (X), policy strategies (L) and metrics of performance (M) related to drought management in the Chindwin River Basin. The XLRM framework for this case study in its initial formulation is presented in table 11.3. Uncertainties that emerged were related to climate change, land-use change and population dynamics. Key policy strategies were identified, including reducing conveyance losses in irrigation, conserving catchments and utilizing groundwater.

Table 11.3. Problems identified for WEAP scenario modeling

Uncertainty (X)	Levers/Strategies (L)	Performance metrics (M)
1) Climate Change - Dry - Wet - Normal	1) Reducing loss in existing irrigation distribution system and using water effectively	1) Water coverage for irrigation, domestic and industrial
2) Land Use Changes - Remain the same - Increase deforestation - Change crop type	2) Catchment conservation/ watershed best management practices	2) Water level for navigation
3) Population growth, migration and human settlement - No change in population - Medium increase - Rapid increase - Slow decrease	3) Sustainable groundwater pumping for domestic and industrial water use	3) Environmental flow

The performance of the selected strategies were measured in terms of water coverage for irrigation, domestic and industrial uses (percentage of water supply compared to water demand), water level in the Chindwin River, and environmental flows (water flows required to sustain freshwater and estuarine ecosystems and livelihoods). The WEAP model was used to assess the impacts of uncertainties and strategies on water availability across the basin and water allocation for different needs through building relationships (R) among the selected X, L, and M components.

A series of discussions with key stakeholder groups was conducted in 2016 to define the scenarios as presented in table 11.4. For the performance indicators, 85 percent coverage was considered as a threshold value of success for domestic, industrial and irrigation water. This value was identified based on discussions during the stakeholder consultation meeting. For water levels, 2.5 m was considered as the minimum water level required for the safe passage of large ships at Monywa. Similarly, for the environmental flow, an 80 percent exceedance of flow based on the historical flow data was considered as a threshold for success.

Table 11.4. Scenario description for the assessment

Scenario	Description
Climate change	1) Dry: Climate projection which has the least rainfall during the projected period (2015–2074) compared with the observed data (1985–2014). Climate projection from RCP 4.5 using CCSM model was selected. 2) Wet: Climate projection which has the highest amount of rainfall during the projected period compared with the observed period (1985–2014). Climate projection from RCP 8.5 using SMHI-RCA4 model was selected. 3) Normal: Climate projection which has rainfall during the projected period (2015–2074) near to the observed data (1985–2014). Climate projection from RCP 4.5 using HadGEM3-RA model was selected.
Land-use change	1) Remain the same: This is a hypothetical case where the current land use remains in place into the future. 2) Increase deforestation: Decrease of forest by 20% by the year 2045 and additional 10% by 2075 was considered for this scenario. 3) Change crop type: Change in crop type includes shifting from conventional crops to more irrigation intensive cash crops and shifting single season paddy to double cropping.
Population change	1) No change in population: This is the scenario where the population is expected to remain constant as in the year 2015 until 2075. 2) Medium increase: A constant annual increase of 0.9% population growth is assumed. This increased rate is based on the historical population growth of Myanmar, there is a current increase of 0.9 per annum which is also considered as a constant growth until 2075. 3) Rapid increase: A constant annual increase of 1.5% population growth is assumed. 4) Slow decrease: Decrease in population might be due to migration of people for better opportunities outside the Chindwin Basin. An annual decrease of 0.5% was assumed as a decrease in the population growth scenario.
Drought management Strategies	1) Reduce loss in the existing irrigation system: This strategy aims to reduce the existing losses by improving the existing distribution network of irrigation and reducing losses in the distribution system. The target is to reduce losses from the distribution network from 40% to 10%. 2) Catchment conservation: Catchment conservation may refer to broad activities involving the watershed best management practices to enforce laws for reforestation in the catchment. As there are a significant number of mining activities in the basin, this strategy aims to enforce laws preventing deforestation and maintaining the forest area for environmental services. This strategy aims to increase reforestation by 30% by the end of the 2070s. 3) Sustainable groundwater pumping: Both domestic and industrial water demand is predominantly dependent on the groundwater supply in the Chindwin Basin. This future strategy aims to increase the withdrawal capacity of groundwater in a more sustainable manner to meet both of these demands mainly in the lower portion of the Chindwin River Basin.

Calibration of the WEAP model

After fine-tuning the parameters related to the soil moisture model, the simulated flow along the Chindwin River at five gauging sites (fig. 11.3) was compared to the observed flow where data was available for the period 1979–2000. The results at the selected three stations (fig. 11.4) show the same trend of observed and simulated flows during the calibration period. However, the peak flows in the wet season at all stations except Hkamti station are slightly overestimated. Overall, goodness of fit statistics indicate the calibrated model performed reasonably well (table 11.5).

Table 11.5. Statistical performances of the model calibration

Statistical Parameters	Hkamti	Homalin	Mawlaik	Kalewa	Monywa
PBIAS %	3.5	-3.6	-7.2	-7.9	-12.8
NSE	0.76	0.74	0.77	0.75	0.68
d	0.94	0.93	0.93	0.92	0.89
r	0.88	0.86	0.88	0.87	0.84
R^2	0.77	0.75	0.77	0.75	0.70

Scenario simulations

Climate change scenarios

Precipitation and temperature changes under three climatic scenarios (dry, wet and normal) resulted in changes in basin-scale hydrologic trajectories. Projected changes under wet and normal climate conditions resulted in an increase in flow at Monywa during all months (see fig. 11.5 a, b), though flows were much higher in June to October than other months, which could increase flood risk if this pattern continues. However, the projected changes under the dry climate resulted in a decrease in monthly lows between May to July. The projected magnitude of changes over the period 2045–2074 is higher than for the period 2015–2044.

Similarly, climate change scenarios also showed a significant impact on groundwater flows as seen in fig. 11.5 (c, d). Under a dry climate scenario, the most adverse impact was observed when compared to the other two climates (i.e. normal and wet).

Figure 11.4. Monthly streamflow calibration (1979–2000) at three selected gauging stations on the Chindwin River

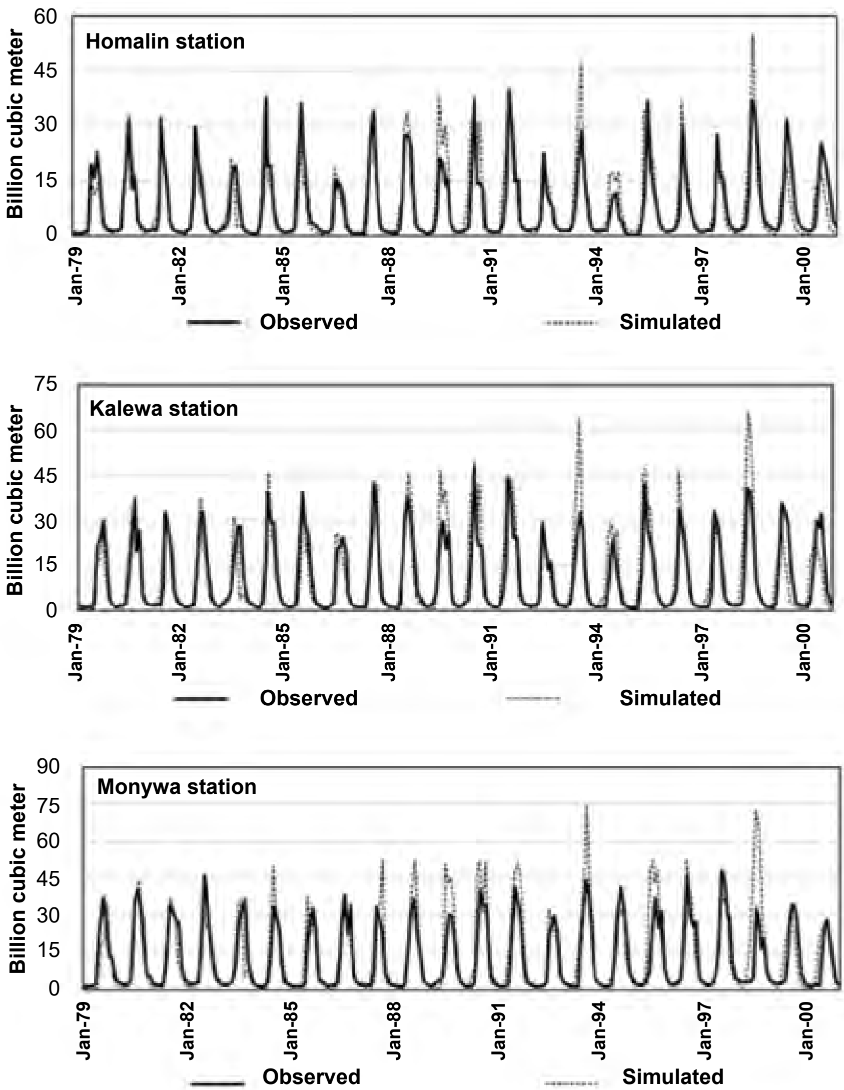
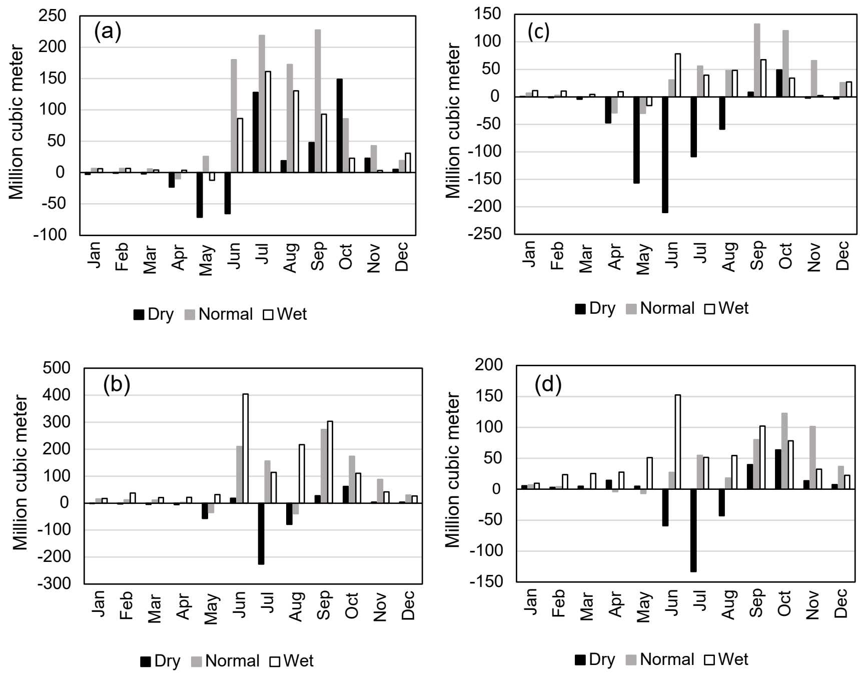


Figure 11.5. Left: Changes in average monthly flow at Monywa station during (a) 2015–2044 and (b) 2045–2074 under climate change scenarios. Right: Changes in average monthly groundwater flows at Monywa station during (c) 2015–2044 and (d) 2045–2074 under climate change scenarios



The monthly groundwater flows were reduced during the same months as the surface flows (March–August). This reduction may impact the livelihoods of those communities who rely on groundwater in the Chindwin River Basin, particularly for domestic and agriculture uses.

Climate change also seems to have an impact on water demand (including both domestic and agricultural demand). The results revealed that especially under the dry climatic conditions, there was an unmet water demand of approximately 16.5 million m^3 from March to May due to lower rainfall over this period.

Land-use change

Figure 11.6. Comparison of surface runoff between baseline and increased deforestation scenario for the Lower Monywa sub-basin

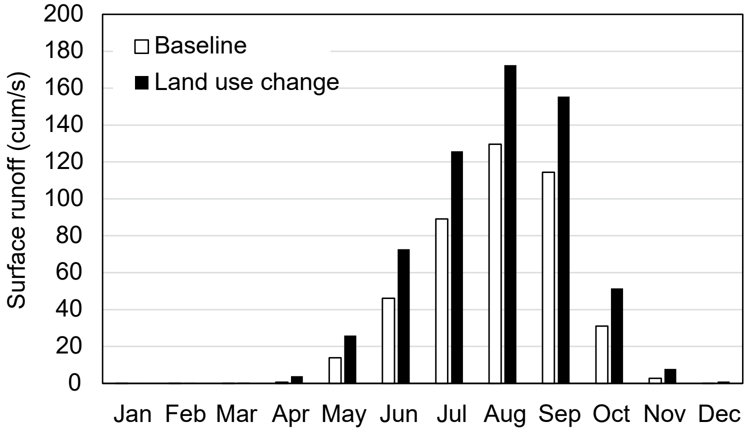


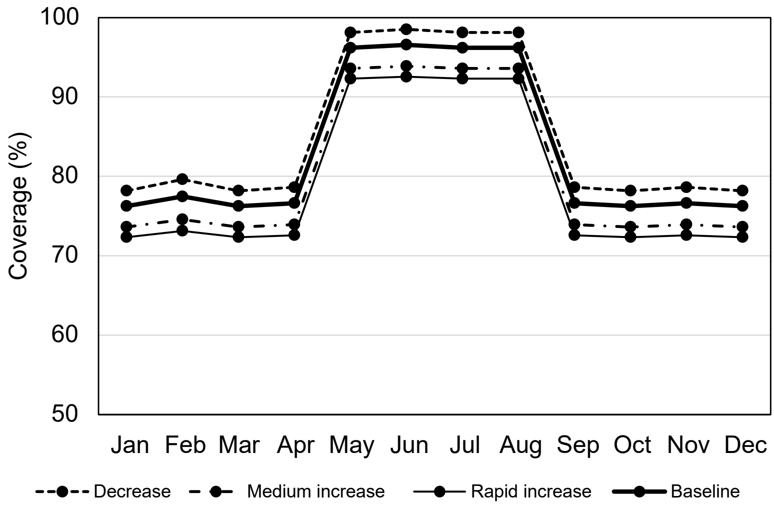
Figure 11.6 presents a comparison of projected average surface runoff for the period 2015–2075 and the baseline in the case of an increase in deforestation for the Lower Monywa Basin. It indicates a significant increase in surface runoff during the wet season (May to October) by 20 to 45 percent under the increased deforestation scenario, when compared with the baseline scenario; this would indicate an increase in the probability of flooding and soil erosion in the future. Deforestation reduces the absorption and water-holding capacity of soils, thereby contributing to greater surface flows into the river/stream networks. Deforestation, mining and expansion of cropland are the main causes of land-use change in the Chindwin River Basin. Based on land-use maps from 1990 to 2013, the loss of tree cover over that period was estimated to be 1,800 km^2 (Krittasudthacheewa et al. 2015).

Both the shifting of conventional crops to more irrigation-intensive cash crops, and the shifting of single season paddy to two seasons in the future (changed crop type scenario), show an increase of evapotranspiration (ET) demand during the dry season (November–April) by 5 to 15 percent compared with the baseline scenario. This will increase demand for irrigation water, particularly during droughts and under the dry climate scenario.

Population change

There is a significant increase in unmet domestic water demand due to a rapid increase in population in the case of the Monywa sub-basin. There is already an unmet demand in the baseline scenario, which means there is a need to reduce this unmet domestic demand. Unmet demand appears to be reduced when there is a decrease in population growth. Population change scenarios seems to be less vulnerable than the other scenarios considered in this study.

Figure 11.7. Domestic water coverage from different population scenarios for the Monywa sub-basin



Similarly, fig. 11.7 provides a comparison of monthly average domestic water coverage for four different population scenarios in the Monywa sub-basin. It is clear that there is a shortage of domestic water in the baseline scenario during the dry season, where after an increase in population, shortages increase significantly during the dry season. The population decrease scenario has the highest percentage of coverage compared to all other scenarios during all months.

Evaluation of vulnerabilities and performance assessment

The vulnerabilities of water resources management in the Chindwin River Basin under various uncertainties were evaluated against performance metrics and thresholds of success as defined in the XLRM framework. Three selected drought management strategies were also examined to assess their robustness under various uncertainties. Robust strategies are those that perform consistently well under the most number of uncertainties, based on the thresholds of success.

Water coverage

Domestic water coverage

Figure 11.8 (see Appendix) presents the vulnerability map for the domestic water coverage for four different sub-basins (Myittha, Monywa, Yinmabin and Lower Monywa). These four sub-basins are in the lower part of the Chindwin River Basin, which is its most densely populated area. All four basins are highly vulnerable to medium and rapid increase in population particularly under dry climate scenarios. The domestic water coverage in Myittha is the most critical even under a decrease in population scenario. It is also noted that vulnerability was significantly reduced when there was already a groundwater strategy in place. Using groundwater has the potential to increase domestic water coverage by 25–62 percent.

Industrial water coverage

Under current management, industrial water coverage for Monywa Industrial Estate will be reduced from 92 percent to 37 percent in a dry climate change scenario. The strategy of pumping groundwater will help to significantly reduce vulnerability.

Irrigation water coverage

Most of the irrigation areas in Monywa and the Lower Monywa sub-basins have irrigation facilities, while most other basins are rain-fed or have limited irrigation infrastructure. Thus, these two sites were considered for analyzing irrigation water coverage (see fig. 11.9, Appendix). The percentage of failure without an adaptation strategy (baseline condition) varies from 15–26 percent under different climate change and land-use change scenarios. A dry climate and a change in crop type scenarios have the most negative impact on irrigation water coverage. The strategy to reduce loss in the irrigation system improves irrigation water coverage in both sub-basins by 4–10 percent. However, the performance of this strategy indicates that it will be unable to cope effectively with a dry climate change scenario (more than 15 percent failure rate).

Water level for navigation

The acceptable water level for safe navigation transport at Monywa is 2.5 m. It was found that there is a significant impact of the dry climate change scenario on declining water level in Chindwin River at Monywa compared with the wet and normal climate change scenarios. The percentage of failure of the water level at Monywa to meet the 2.5 m threshold is approximately 30 percent for 2015–2074. The simulated results clearly shows that the three selected strategies indicated in fig. 11.10 (see Appendix) will not improve water levels in the Chindwin River during the dry season for navigation.

Environmental flows

The study set the threshold of maintaining environment flows at 80 percent flow exceedance along the Chindwin River. Figure 11.10 (Appendix) presents the vulnerability map of environmental flows under different climate change and land-use change scenarios. It is evident that environmental flow is more vulnerable under the dry climate change scenario for all locations. The percentage of failure of environment flows under the dry climate change scenario is higher than the acceptable level (more than 20 percent of failure over the study period), while environmental flows under wet and normal climate change scenarios are observed at an acceptable level. Environmental flows at Mawalaik are the most vulnerable compared with other locations. Land-use change scenarios have slightly negative impacts on environmental flows. However, the watershed conservation strategy (by increasing reforestation) does not perform in such a way as to improve environment flows under climate change and land-use change uncertainties at the basin scale, as reforestation will only increase the total basin forest cover by 10 percent. Also, increasing reforestation in the watershed could potentially lead to a decline in river flows and base-flows due to young trees consuming a greater volume of water due to the size of their canopies and the growth phase (Cunningham et al. 2015). Therefore, this strategy may not be successful if the objective is to increase the water yield in the catchment.

Conclusion and recommendations

The projected changes under wet and normal climate change scenarios indicated an increase in flows along the Chindwin River, particularly during the wet season from June to October (more so than other months), which would probably increase flood risks in the future. However, the projected changes under a dry climate scenario resulted in a decrease in flow from May to July, with an increased risk of drought. The significant increase in the surface runoff in the Lower Monywa sub-basin during the wet season (May to October) by 20–45 percent under an increased deforestation scenario, when compared with the baseline scenario, increases the probability of flooding and soil erosion. Shifting the single season paddy to two seasons in the future (change of crop type scenario) indicated an increase of evapotranspiration (ET) demand during the dry season (November to April) by 5–15 percent compared with the baseline scenario. Notably, the study projects domestic water shortages, especially in the dry season, if the basin's population increases rapidly.

Using groundwater is an effective strategy to improve domestic and industrial water coverage under various uncertainties. Pumping groundwater has the potential to increase domestic water coverage in Myittha, Monywa, Yinmabin and Lower Monywa sub-basins by 25–62 percent, and to increase industrial water coverage for Monywa Industrial Estate by 54 percent. Reducing water losses in the irrigation system is projected to improve irrigation water coverage in Monywa and Lower Monywa subbasins by only 4–10 percent. This suggests that all three selected strategies will not improve the maintenance of water levels in the Chindwin River during the dry season for navigation and environmental flows. Consequently, alternative strategies and measures, such as increasing water storage, wetlands and flood retention measures, should be sought and investigated to address this issue.

One limitation of this analysis should be highlighted: the Chindwin River Basin is a large basin and most of the modeled sub-basin's areas are greater than 3,000 km^2, while the selected strategies were not basin-wide in scale. Further in-depth analysis of drought and water scarcity issues in the lower part of the Chindwin River Basin is needed.

Finally, the policy review suggests that insufficient strategic policy attention has been given to issues of drought and water scarcity in Myanmar. Previous responses to drought and water scarcity have been tied to projects at specific locations. Awareness of drought, its destructiveness, and appropriate policy responses merit serious and sustained attention as well as strengthened collaboration among different actors involved in water resources development and management.

Acknowledgments

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12

Application of Robust Decision Support (RDS) for water scarcity management in Northeast Thailand

Chusit Apirumanekul, Manish Shrestha, Yanyong Inmoung, Ratchapat Ratanavaraha and Jutamas Kaewsuk

Over the last decade, Thailand has been experiencing more frequent and intense drought events, affecting the level of water storage in reservoirs and resulting in insufficient water supplies for agriculture during the dry season. Northeastern Thailand is one of the most water-scarce areas in the country, vulnerable to droughts and water insecurity. In this region, the Huay Sai Bat River Basin has been experiencing ongoing water shortages that affect both farming livelihoods and household consumption. Identifying a long-term solution for water scarcity management that can prove robust under a wide range of uncertainties, including climate change, is crucial for water resources management in this region.

This study assesses the application of the Robust Decision Support (RDS) framework in the Huay Sai Bat River Basin to explore the feasibility of multiple drought management policies under a wide range of uncertainties, including climate and land-use change. Water allocation and water uses in various sectors, such as in agriculture, households, industry and the environment, were estimated by utilizing the Water Evaluation And Planning (WEAP) system under various scenarios developed through a series of consultative meetings. Four plausible water strategies (increasing natural retention storage, change of crop types, use of groundwater as an alternative source and check dam construction) were evaluated based on specified thresholds in four sectors (agriculture, domestic, industry and environment) under three climate conditions (dry, normal and wet). Among the strategies identified, the use of groundwater as an alternative source was considered a potential option in combating water scarcity in the basin. Further studies are needed to explore the feasibility of groundwater as a potential sustainable water source.

Drought management in northeastern Thailand

Droughts in Thailand have recently become more frequent and severe, affecting the level of water stored in reservoirs and affecting dry season farming. Meeting the increasing water demand for dry season agriculture, especially irrigated rice farming, is a major challenge for state agencies who also have to allocate water to other key sectors such as households, industry and environmental services.

Northeastern Thailand is considered one of the most impoverished agricultural regions in the country. The region has often experienced inter-and intra- annual drought periods. Climate change is considered to be the major cause of rainfall variation in the region. Average temperatures in northeastern Thailand are expected to increase by 2°C by 2050, which will result in significant stress on agriculture and other livelihood activities (Cadena et al. 2014). Changes in rainfall patterns combined with a shift from monsoon season crops (e.g., lowland rice, cassava) to rubber production, will also have an impact on water availability and demand (ibid.).

Huay Sai Bat, a sub-river basin of the Chi River Basin, is recognized as one of the most drought-prone areas in the northeast. The Huay Sai Bat communities, particularly in the upper and middle reaches of the basin, often face water shortages during the dry season as the water supply for irrigation and household consumption is severely limited.

The Government of Thailand deals with droughts under its disaster management and drought relief plans, and hence state policy mainly focuses on emergency response (Franzetti et al. 2017). Drought relief policies and plans that have been developed at the provincial and district levels are likewise linked to the national disaster relief. The national strategy guides provinces to organize drought relief actions annually, i.e.: a) establish an ad hoc provincial drought relief committee; b) prepare to make an announcement declaring a 'disaster area'; and c) set up an information and communication channel between communities and government agencies. With limited resources available locally, most communities largely rely on provincial drought relief activities, most of which are short-term solutions.

For example, to resolve water shortages during the dry months in Huay Sai Bat, provincial and district government agencies respond by sending water trucks to affected communities for domestic water use. Provincial and district authorities have also explored measures to extract groundwater for household and farm use. However, some recent efforts have attempted more long-term water management measures to address Huay Sai Bat's drought vulnerability. A study, "Exploring Northeast Thailand Futures: Nexus of Water, Food and Energy" (SEI 2012), focused on exploring the long-term climate consequences and possible livelihood options for the area. Another study, initiated in 2013, "Improved management of extreme events through ecosystem-based adaption in watersheds (ECOSWat)," a joint study between the Department of Water Resources (DWR), Rajamalanga University of Technology Isan (RMUTI), and the German International Cooperation (GIZ) recommended and proposed a combination of infrastructure and non-infrastructure measures (GIZ 2015). The study advised the building and expanding of existing reservoirs and agricultural zoning to mitigate climate change impacts on water resources. However, there remains no comprehensive strategy and no assessment on how proposed mechanisms would perform in combating water scarcity in Huay Sai Bat.

Management strategies need to be robust and perform well under a range of likely uncertain future developments. Indeed, there may be a need to diversify water management measures (Pahl-Wostl et al. 2004). Broadly, the technical complexity and social embeddedness of various aspects of water resource management require the collaboration of public authorities, scientific experts, groups of users, non-governmental organizations and representatives of stakeholders in a particular ecological domain (Bouwen and Tharsi 2004). The present study applies the RDS framework to identify a long-term solution for water scarcity management involving stakeholders under a wide range of uncertainties. In addition, the RDS framework incorporates data visualization tools for presenting scientific results to decision-makers. Using the visualizations, scientists and decision-makers can navigate the decision space and potential objective trade-offs to facilitate discussion and consensus building (Forni 2016).

The overall objective of this study is to explore appropriate strategies, policies, and projects for water scarcity through a participatory approach based on the RDS framework. Key partners in this study included government agencies related to water resources management, academic institutes, local government, a community service organization and the Huay Sai Bat River Basin Committee. The study explored the following research questions:

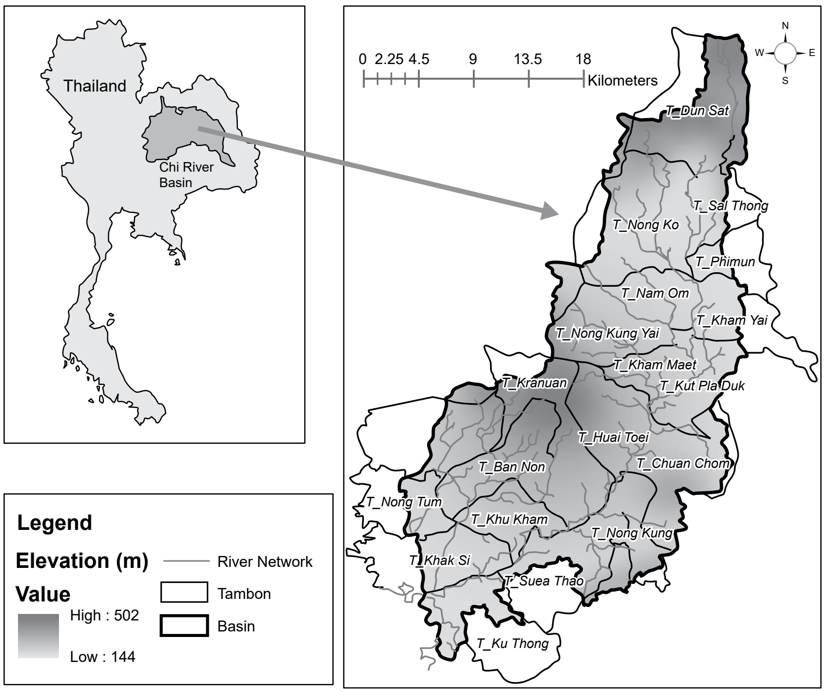
- What water scarcity policies and strategies exist at the national and subnational levels, and what are the gaps in those strategies related to drought management?
- What are the projected impacts of climate change on water availabilities in Huay Sai Bat River Basin?
- How will different water-related policies (related to, for e.g. land-use change, use of groundwater, etc.) impact water allocation in the basin?
- What are appropriate water-related policies and strategies for water resources management under a wide range of uncertainties in the basin?

Study area

Huay Sai Bat River Basin is classified by the DWR and the Royal Irrigation Department (RID) as being a chronic or persistent water shortage area (fig. 12.1). The Basin has an area of 741 km^2 and maximum elevation of 550 meters above sea level (masl). The basin's features are similar to other Mekong sub-basin highlands, with mostly sandy soil of low fertility covering about 70 percent of the basin, with scattered pockets of salinization occurring in 8 percent of the area. The average annual rainfall is around 1,032 mm, which is well below the northeast region's 1,250–2,000 mm producing an average discharge of 4.25m^3/s (GIZ 2015). The upper and middle zones of the Huay Sai Bat Basin experience water shortages annually, while the lower portion of the basin faces intermittent seasonal flooding. The main activities in Huay Sai Bat are agricultural (72.35 percent), mainly rice, sugarcane, cassava and corn.

The Huay Sai Bat River Basin covers three provinces, Khon Kaen, Kalasin, and Mahasarakham, with an approximate population of 65,000 (GIZ 2015). Existing water allocation infrastructure includes one large-scale dam and thirty-seven small-scale dams which can irrigate 16 percent of the total area. Additional water is transferred from the Nam Phong River via a large irrigation canal. Around 72 percent of the total area is used for agriculture, 16 percent is covered by forest, and 4 percent by urban settlements. Rice yields in the Huay Sai Bat River Basin are on average 473 kg per rai (2.96 t/ha) while the national average is 529 kg per rai (3.31 t/ha). The investment costs associated with rice production are predominantly labor (30 percent) and chemical fertilizer (35 percent).

Figure 12.1. Location of Huay Sai Bat River Basin



Methodology

The study applied the RDS framework to support water scarcity management under various projected uncertainties. The RDS framework integrates different tools and approaches including repetitive multi-stakeholder engagement during implementation. The study uses mixed methods which include: a) literature reviews; b) interviewing stakeholders and key informants; c) organizing expert group meetings and workshops; and d) data collection from existing studies, reports, online information and books. Major activities performed under each step of the RDS framework are explained in fig. 12.2.

Once the stakeholders concerned with water scarcity management in the Huay Sai Bat Basin were identified, the process continued with exploring the factors that impact water resources management, including indicators to evaluate performance of water-related strategies and policies through the XLRM framework (fig. 12.3). The XLRM framework consists of four major components:

X - External factors or Uncertainties: These are factors outside the control of water users but have impacts on water resources management, such as climate change, land-use change, population growth, etc.

L - Levers or Strategies: This component includes management strategies, policies, options or projects that can be applied to improve water resources management, such as reservoir construction, change of dam operation, change of crop type, etc.

R - Relationship or Model: This component represents analytical tools or models, such as the WEAP model, that simulate linkages between the uncertainties and strategies and their impacts on the system.

M - Performance Matrices or Indicators: The final component is the indicator or threshold that is set by decision-makers to evaluate performance (success or failure) of various management strategies/policies/options. For example, performance indicators could include water demand per day for domestic consumption (liter per capita per day), minimum flow at certain points (m^3/s), reservoir storage in specific month (m^3), etc.

A series of consultation workshops and meetings were organized in collaboration with key boundary partners during the implementation of the project (fig. 12.4). Representatives from relevant agencies and key boundary partners were invited to participate in regional and national workshops and consultation meetings to share their experiences and knowledge on water scarcity management. Continuous engagement and close collaboration leads to enhancing capacity and raising awareness of boundary partners and relevant agencies on the application of RDS to address uncertainties in water resources management and planning.

Figure 12.2. Robust Decision Support (RDS) framework with key activities

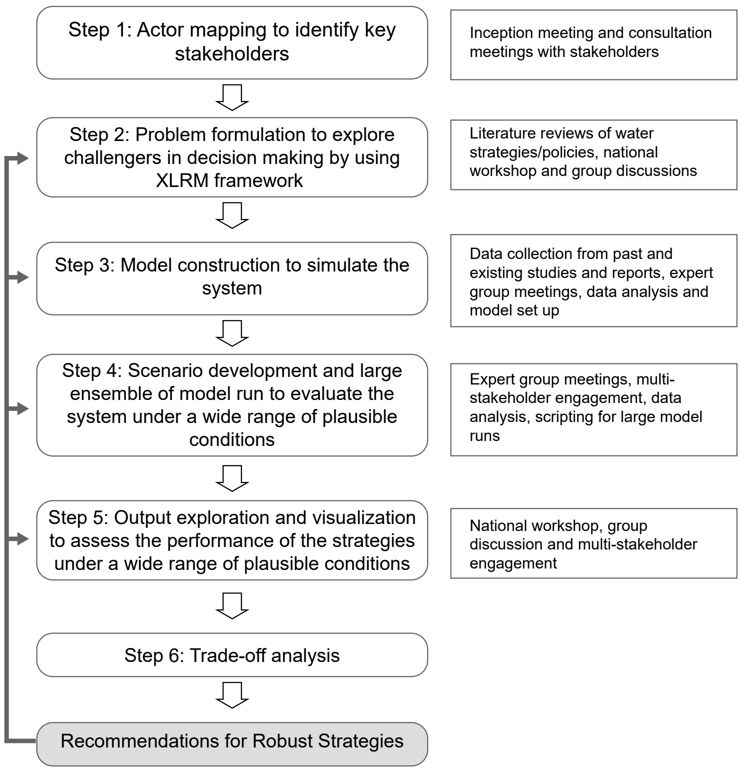
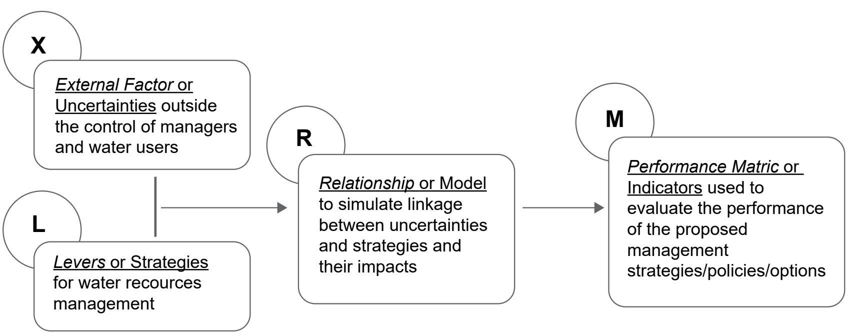


Figure 12.3. XLRM framework



Key boundary partners in the present study included: DWR, RID, Department of Disaster Prevention and Mitigation, Provincial Waterworks Authority, Department of Groundwater Resources, Provincial Office, Huay Sai Bat River Basin Committee, and local government authorities (e.g. head of Sub-District Administrative Office and village heads) in Huay Sai Bat River Basin, tertiary institutions (e.g. Mahasarakham University and RUTI).

Figure 12.4. Workshops and meetings with key boundary partners

Top: First regional workshop to introduce RDS framework (July 2015).

Bottom: Final national workshop for disseminating results of RDS application in Huay Sai Bat River Basin and discussing policy implication (August 2016).

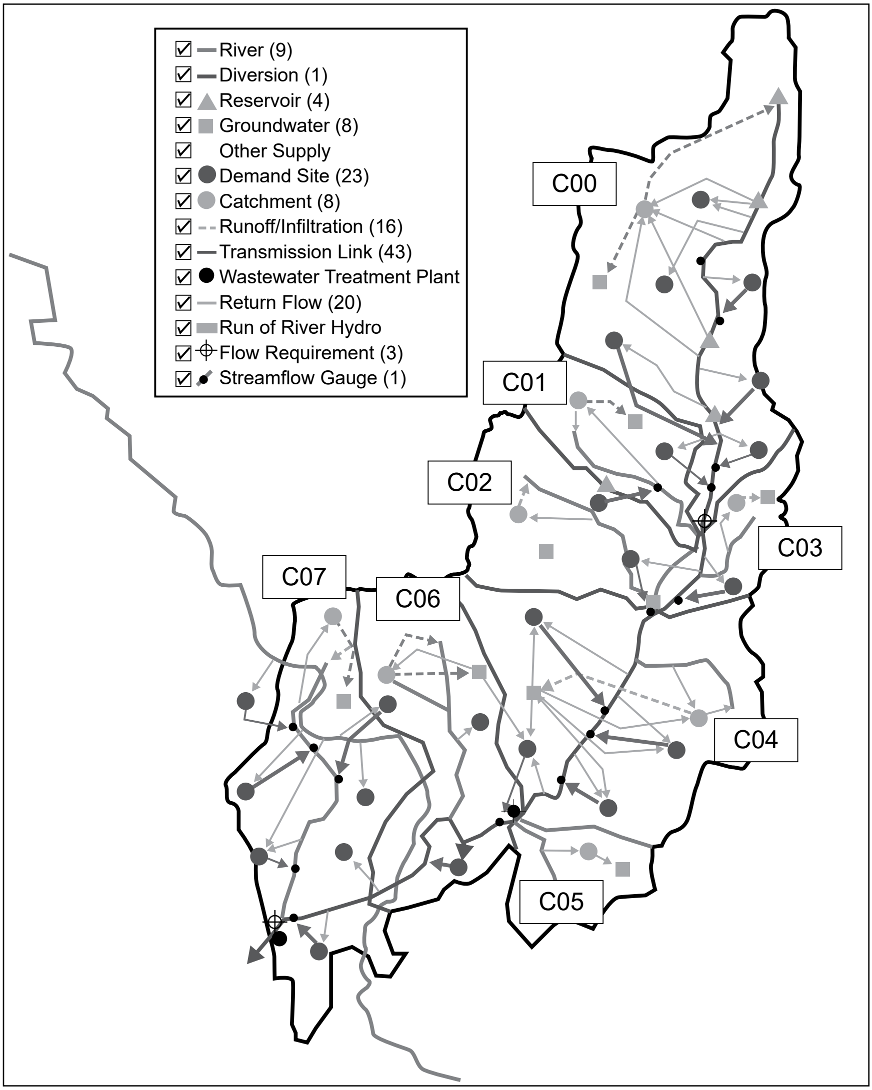
The WEAP model was used to simulate the water allocation process in the Huay Sai Bat River Basin. The model can be used to assess demand and supply together with hydrological simulation and human interventions for integrated water resources management (IWRM) planning. The WEAP model was used to facilitate scenario impact assessments for a wide range of options, including climate variations, watershed management, land-use change, infrastructure development and other factors, in Huay Sai Bat Basin. The basin was divided into eight sub-catchments based on topography and the river network. Major water sources (rainfall, retention storage, irrigation schemes and groundwater), water demands (e.g. domestic and agriculture), and water-regulating infrastructure (e.g. cascade weirs) in Huay Sai Bat River Basin were simulated by the WEAP model (fig. 12.5). The model incorporated domestic water consumption for each sub-district, agricultural water demands in all eight sub-basins, and industrial water requirements in sub-basins C00, C06 and C07. To sustain the freshwater ecosystems and livelihoods of people who rely on these ecosystems a minimum quantity of flow is required in the river. To represent this, three points (C00, C06 and C07) representing the minimum flow in the river are included in the model.

Results and discussion

Policy review

In Thailand, flood management has received significant policy attention, especially after the 2011 floods which are considered the fourth costliest disaster in the world (Franzetti et al. 2017). Moreover, in the last decade, Thailand has experienced more frequent and intense droughts affecting the level of water in reservoirs, resulting in insufficient water for domestic consumption and agriculture during the dry season. Thailand has, for a considerable period, faced the challenge of not having a long-term comprehensive water resources management strategy in place to support planning and effective responses to such events. One problem is the existence of muliple agencies responsible for water management. There are seven ministries and thirty departments with responsibilties for water development projects across the country, but there is little coordination between them.

Figure 12.5. Water Evaluation And Planning (WEAP) model diagram of the Huay Sai Bat River Basin



Since 2015, Thailand has been following the National Strategic Plan on Water Resources Management (NSPWRM) for 2015–2026, developed by the National Committee on Water Resources Policy. The NSPWRM 2015–2026 aims to support water-related agencies in implementation plans as well as forging integrative actions among agencies. There are six strategic actions that have been identified for implementation: (i) water supply for community consumption, (ii) water security for production sectors (agriculture and industry), (iii) flood management, (iv) water quality management, (v) conservation of headwater forest and soil erosion prevention, and (vi) internal institutional arrangement. It should be noted that the NSPWRM 2015–2026 does not clearly declare any strategic action or measure on water *scarcity*, but uses the term "water security" instead. The strategic actions as listed by the NSPWRM's strategic plan have a strong focus on building more water infrastructure, expanding irrigation systems, and conserving water use. Unlike drought mitigation, flood prevention and management are clearly outlined by the NSPWRM, which stresses the improvement of water channelization and drainage systems, as well as the improvement of water retention areas.

The NSPWRM 2015–2026 is limited to the central government, which assigns various departments to perform specific functions (i.e. developing water infrastructure projects). The NSPWRM does not cover the provincial and district governments, but assigns them to carry out a range of public services, including water resources management, on an area-based mandate.

Currently, several agencies at the sub-national level are responsible for water resource development in parallel with other agencies. There is clearly a need for greater coordination among agencies to avoid duplicated efforts. The NSPWRM is expected to assist water agencies working in close cooperation and in avoiding overlap and duplication of efforts. The NSPWRM also states the need for a National Water Resources Act; drafting of this Act commenced in 2015 and is still in progress. The NSPWRM further states a plan to reform the currently 30 water-related agencies through redefining or amalgamating their roles at the national and river basin levels.

In February 2015, Thailand's Council of Ministers established the Integrated Plan for Drought Management for 2015 to respond to severe drought-induced water shortages with a budget of THB7.8 billion (US$236 million). There are four aspects to the plan: the prevention of droughts and mitigation of the adverse effects of drought; preparation of disaster relief programs; establishing an emergency operations center and; post-disaster management and financial compensation for drought-affected communities.

This plan focuses on short-term interventions without envisaging any long-term vision to solve the problem. Even though there is a significant budget, the allocation of these resources seems likely to focus more on responding to disasters rather than trying to prevent them. Financial compensation will be provided to affected people, rather than spending on drought prevention and mitigation through the use of technology and developing infrastructure for long-term solutions such as: expanding irrigated areas; building small reservoirs in arid areas to store more rainwater during the wet season; improving existing waterways/storage capacities; and developing a model for drought management and early warning systems.

Problem formulation using the XLRM framework

Key inputs from the application of the XLRM framework were obtained through a series of workshop and consultation meetings with the participation of key state agencies and other stakeholders. Two main uncertainties (climate change and land-use changes) were identified. Four potential water resource management policies were also identified during the workshop. Along with these strategies, "business-as-usual" (i.e. when there is no effort to address the uncertainties) was also added to the proposed strategies. Four sectors (agriculture, domestic, industry and environment) that impact the implementation of water resources policies were used to define the outputs of the XLRM framework (summarized in table 12.1).

Table 12.1. Summary of XLRM findings for Huay Sai Bat Basin

<table>
<tr><th>Uncertainties (X)</th><th>Water Resources Strategies (L)</th></tr>
<tr><td>A. Climate Change
1. Average/Normal Climate
2. Dry Climate
3. Wet Climate
B. Land-use Change
1. Sugarcane to rubber in upper region and rice to sugarcane in middle region
2. Expansion of irrigation in lower region
3. Combination of both 1 and 2</td><td>S0: Business as usual
S1: Dredge existing swamp for retention purpose (Nong Yai)
S2: Use of groundwater as an alternative water supply
S3: Shift the crop calendar
S4: Cascade weir construction in the upper region</td></tr>
<tr><th>Relationship or Models (R)</th><th>Metrics of Performance (M)</th></tr>
<tr><td>
</td><td>A. Agricultural water coverage
B. Domestic water coverage
C. Industrial water coverage
D. Environmental / Ecological flow</td></tr>
</table>

Note: Water coverage is the percentage of water demand that was fulfilled. The coverage cannot exceed 100%; Environmental or ecological flow is a minimum river flow that needs to be maintained for environment or ecology purposes.

Climate change analysis

To cover uncertainties in climate models, multiple Regional Climate Models (RCMs) were selected to analyze future climate projections for Huay Sai Bat River Basin. This study uses eight RCMs (table 12.2) under two Representative Concentration Pathways (RCPs); RCP 4.5 and RCP 8.5 scenarios from the Coordinated Regional Downscaling Experiment (CORDEX) East Asia and South Asia portals, which has a spatial resolution of 0.440 (approximately 50 km by 50 km). Two climate variables (precipitation and temperature) were analyzed. Linear Scaling bias correction was used to correct the underestimation and overestimation of precipitation during the wet and dry seasons, respectively.

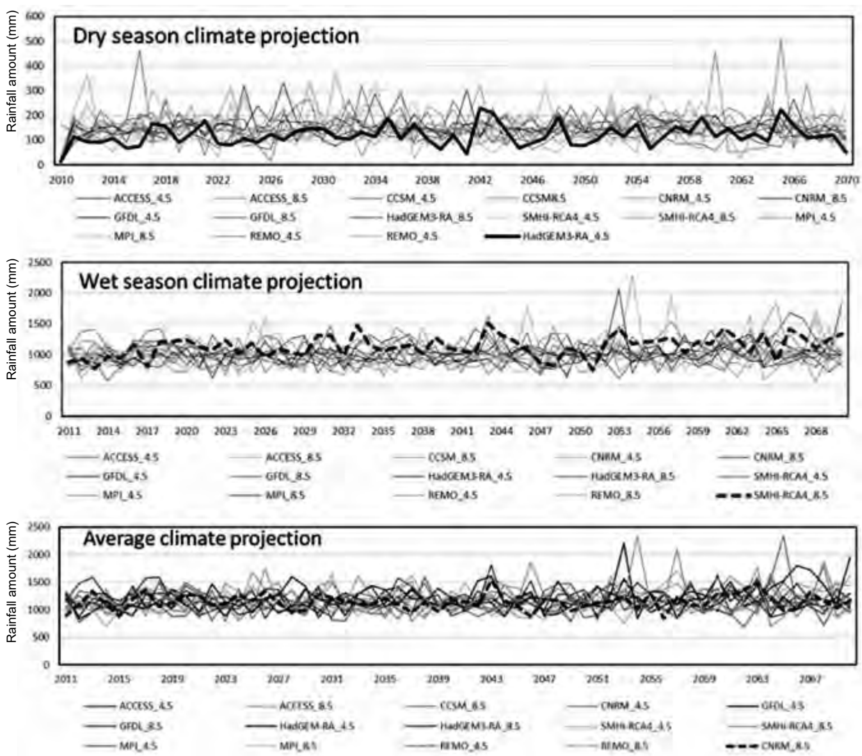
The baseline climate for this study is the period 1980 to 2010. Three future climate models were considered for the assessment: (a) average/normal climate; (b) dry climate and (c) wet climate based on the projected period, 2011 to 2070.

Table 12.2 Regional Climate Models (RCM) used for future climate projection (2011–70)

No.	RCM	Driving GCM	Links
1	HadGEM3-RA	HadGEM3 of the Met Office Hadley Center (MOHC)	https://cordex-ea.climate.go.kr/
2	CCAM(ACCESS)	ACCESS1.0	http://cccr.tropmet.res.in/
3	CCAM(CNRM)	CNRM-CM5	
4	CCAM(CCSM)	CCSM4	
5	CCAM(GFDL)	GFDL-CM3	ftp link : ftp://cccr.tropmet.res.in/iRODS_DATA/CORDEX-Data/
6	CCAM(MPI)	MPI-ESM-LR	
7	SMHI-RCA4	ICHEC-EC-EARTH	
8	REMO2009	MPI-ESM-LR	

To identify dry climate conditions, the average dry season rainfall for the baseline period (1980–2010) was calculated and then compared with the dry season rainfall of all the 16 climate scenarios (8 RCMs X 2 RCP) for each year from 2011 to 2070. The RCM that represents dry climate condition was identified by selecting the top-ranking RCM that has the total number of years with dry season rainfall (2011–2070) less than the average dry season rainfall from baseline (1980–2010). Similarly, the wet climate model was selected from the top-ranked RCM with the number of years (annually estimated during 2011–2070) where the wet season rainfall is higher than the average wet season in the baseline. Finally, the normal climate model was identified by finding the climate projection which most closely resembles the baseline historical data. HadGEM3-RA 4.5, SMHI-RCA4_8.5 and CNRM_8.5 models were selected as dry, wet, and normal season rainfall models for analysis, repectively (fig. 12.6).

Figure 12.6. Projected average annual rainfall from eight Regional Climate Models (RCMs) under RCP 4.5 and 8.5 for normal, dry and wet climate model selection for the entire basin



Average annual rainfall over eight sub-basins were estimated for baseline and projected periods for normal, dry, and wet climate conditions. The comparisons between rainfall for the baseline and projected periods in percentage were also estimated (table 12.3).

Table 12.3. Rainfall and percentage change between baseline and projected period for normal, dry and wet climate conditions in Huay Sai Bat Basin

Sub-basin	Annual rainfall (mm) for baseline (1981–2010)	Change (%) for projected period (2011–70) compared with baseline rainfall		
		Dry	Normal	Wet
C00	1,217	-4.1	-3.0	6.7
C01	1,215	-4.0	-4.3	6.5
C02	1,209	-4.4	-4.8	6.0
C03	1,221	-3.6	-3.8	7.0
C04	1,197	-3.5	-4.0	7.0
C05	1,197	-3.3	-3.8	7.6
C06	1,185	-3.0	-4.7	6.3
C07	1,181	-2.9	-4.7	6.5

Land-use change

Three future land-use scenarios were considered based on consultation meetings with relevant agencies and experts in Huay Sai Bat River Basin. In the first scenario, existing sugarcane growing areas will be converted to rubber plantations in the upper region (C00) and rice fields will be converted to sugarcane in the middle region (C01, C02, C03, C04 and C05). The land-use change in the first scenario starts from 2011 with linear reduction to 2070. By 2070, it is assumed that all changes will be completed (i.e. only rubber plantations in C00 and only sugarcane in C01–C05). For the second scenario, the irrigation area in the lower basin (C06 and C07) will be expanded from 44.2 km^2 in 2010 to 57.3 km^2 by the year 2070 (i.e. all the rainfed irrigated rice fields will be converted to irrigated rice fields in 2070). The third scenario combines both scenario 1 and scenario 2. Another scenario without any change in land-use is also added into consideration, making a total four land-use scenarios in the analysis.

Water scarcity management

Four possible water scarcity management strategies were identified by local authorities and relevant agencies during national workshops. The strategies are described below:

- Dredging the existing retention storage (at Nong Yai) to increase its storage capacity from 0.8 million m^3 to 2.5 million m^3.
- Using groundwater as an alternative source of water supply for small-scale irrigation in sub-basins C04 and C06.
- Shifting the crop calendar by starting the planting of rice one month later than currently practiced (i.e. changing the start of the season from May to June).
- Constructing small cascading weirs along the river in the upstream of Huay Sai Bat River Basin from 2020.

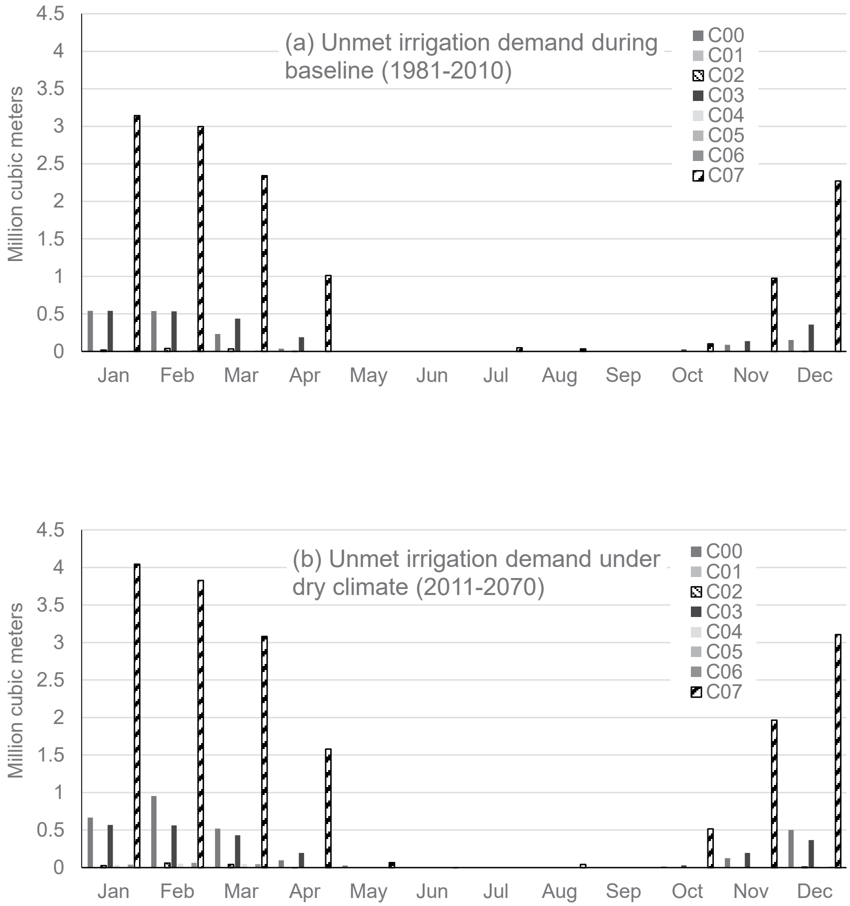
Along with these strategies, business-as-usual (i.e. when there is no effort to address water uncertainties) was added making a total of five possible strategies.

A total of 60 scenarios for the WEAP model simulation were developed from the outputs from the XLRM framework (3 climate scenarios x 4 land-use change scenarios x 5 water-related strategies). The results from the WEAP simulations were analyzed for all 60 scenarios. For brevity, selected analysis results are discussed below. The dry, wet, and normal climate data and land-use changes were used as input to the calibrated model and the discharge at the outlets were simulated and compared. The annual runoff in the future is predicted to change within the range of -15 percent to 9 percent from the baseline period. The percentage change in annual runoff between baseline and project periods for normal, dry, and wet climate conditions is presented table 12.4.

Table 12.4. Percentage change in annual runoff between baseline and project periods for normal, dry and wet climate conditions

Sub-basin	Annual runoff (million m^3) Baseline (1980–2010)	Annual runoff change, 2011–70 (%)		
		Dry	Normal	Wet
C00	64.3	-14	-15	1
C01	18.1	-12	-9	4
C02	24.2	-15	-11	4
C03	10.7	-15	-9	7
C04	168.6	-13	-11	4
C05	11.6	-9	-6	9
C06	210.2	-17	-14	1
C07	251.5	-17	-13	2

Figure 12.7. Unmet water demand for irrigation sector during (a) baseline and (b) future dry climate conditions at the sub-basin level



A long-term monthly simulation indicates no shortage for domestic and industrial water demand while there is a water shortage for the irrigation sector within the baseline scenario and projected period 2011–2070 (fig. 12.7). This is due to the approach taken in water allocation where priority was given to domestic and industrial use rather than irrigation. Under dry climate conditions, the irrigation sector in the future may face greater water shortages during the dry season in comparison with the baseline. When considering only climate change and land-use changes in Huay Sai Bat River Basin, annual unmet demand for irrigation increases from 16.8 million m^3 to 23.8 million m^3 (41.7 percent increase on average). Figure 12.7 presents the unmet water demand[1] for the irrigation sector for all sub-basins for the baseline and future dry climate conditions.

Results from RDS application

To evaluate the performance of the proposed water scarcity management strategies, thresholds of different indicators were used to consider the success or failure of these water strategies. These thresholds of indicators were identified during multi-stakeholder national workshops and consultation meetings. Recommended thresholds for performance evaluation were discussed among local experts and relevant agencies. The thresholds for indicators were modified, and there were several suggestions for thresholds to be used for strategy performance assessment (e.g. amount of water required to irrigate a rice crop per rai, amount of water demand per capita per day for domestic consumption, minimum streamflow that needs to be maintained in the river for environmental purposes, etc.). During the final consultation meeting with local experts and local authorities, it was recommended that water coverage for domestic, agricultural and industrial use, and the exceedance probability of minimum flows at specific river locations, should be used to evaluate the performance (success or failure) of the five identified strategies.

Each strategy was assessed by first, evaluating its likely success or failure, and second, evaluating its robustness. The first step of evaluation determines whether the proposed strategy would be useful to improve the value of indicators being considered to at least meet acceptable thresholds during the specified regular period (monthly), whereas the second step of evaluation determines its robustness to address uncertainties over a long period.

Several water coverage thresholds were used to determine if the strategy was a success or failure. Table 12.5 presents water coverage thresholds used for determining the success of a range of water resource strategies for domestic, agricultural, industrial and environmental use. At each step of the WEAP simulation, monthly in this case, water coverage as a percentage for different sectors was calculated. Water coverage for each sector was then compared with the recommended threshold to determine if it failed. The ratio of the number of times water coverage in each sector was unmet for the entire simulated period was calculated for each strategy and compared with the suggested robustness (ratio of failure) to decide if the strategy is robust or not.

To evaluate the performance of a water strategy for the environmental sector, the WEAP model was run under a wide range of uncertainties (climate and land-use change). Results from WEAP simulations (river discharge at minimum flow points for the environmental sector) were extracted and compared with the threshold to determine if the strategy was successful or failed at each simulation period (month). The river discharge of 0.27 m^3/s at the sub-basin C00 outlet was used as a threshold for the minimum stream flow requirement for the environmental sector. For example, if there are 40 months that simulated river discharges below 0.27 m^3/s at the C00 outlet during the project period simulation (2011–2070 or 720 months), the ratio of failure is 0.056 (40 failed months/720 total months), which is considered robust since the ratio of failure is lower than 20 percent (from the robustness threshold of the environmental sector in table 12.5).

Table 12.5. Indicators and thresholds for performance evaluations of water scarcity strategies in Huay Sai Bat River Basin

Sector	Indicators	Criteria/Threshold	
		Success	Robustness (ratio of failure over evaluation period)
Domestic	water coverage (%)	Equal to 100%	Lower than 3%
Agriculture	water coverage (%)	Greater than 80%	Lower than 20%
Industry	water coverage (%)	Greater than 80%	Lower than 5%
Environment	Minimum streamflow at specific points (m^3/s)	Greater than 80% exceedance flow value	Lower than 20%

The robustness of the different strategies was assessed under different climate conditions and land-use change conditions for all sub-basins. The performance of the water management strategies were evaluated in four sectors (domestic, agricultural, industrial and environmental). The performance matrix for all four sectors are presented in figs. 12.8 to 12.11 (see Appendix).

Domestic sector

As the highest priority, the domestic sector's robustness criteria (acceptable ratio of failure) was selected as 3 percent. If the ratio of failure is less than 3 percent, the color of the cell in the matrix is shown as green, whereas the ratio of failure greater than three percent is shaded red. Figure 12.8 (Appendix) presents the performance matrix of the domestic sector for six sub-districts under a range of uncertainties including climate and land-use change (rows) for each management strategies (column). These sub-districts lie in the upper part of the basin, which are more vulnerable as water is less available compared to the middle and lower parts where there are no water shortages.

During normal and wet climate conditions, water coverage for domestic consumption falls under the acceptance level, irrespective of any changes in land use and water management strategies. For dry climatic conditions, the water deficit increases and the ratio of failure is higher than the acceptable threshold, ranging from 3 to 5 percent, for no land-use change and for the expansion of irrigation in the lower region of the basin. Shifting the crop calendar (strategy 3 – S3) seems to have an impact on water coverage for domestic consumption in the sub-districts in the upper basin, irrespective of any land-use change.

For the land-use change scenarios (converting sugarcane land to rubber in the upper region and converting rice to sugarcane in the middle region), there seems to be no impact on domestic water demand coverage in these sub-districts due to less water being required for irrigation in both cases. Among all four proposed strategies, increasing the existing retention storage (i.e. Nong Yai swamp) by dredging it is likely to be an appropriate solution for the water domestic sector in the mentioned sub-districts. When water retention capacity is increased, there will be more water available for supply to other sectors (e.g. irrigation, industry, etc.), thus reducing water sharing from the domestic sector.

Industrial sector

Based on the consultation meeting, the acceptable failure ratio was set at 5 percent. The dry climate scenario will have the highest impact on the water available for the industrial sector, whereas no impact is seen due to land-use and crop type change scenarios. This suggests that the water availability for industrial demand in the basin is likely to rely on prevailing climatic conditions fig. 12.9, Appendix. All four identified water management strategies, including the business-as-usual scenario, have acceptable performances for normal and wet climate conditions. For the dry climate scenario, shifting the crop calendar seems to have some impact on water availability for industrial sector, which still does not exceed the level of acceptable failure ratio (5 percent). Under climate change and land-use change scenarios, all water strategies perform well, while Strategy 3 (shifting crop calendar) produces slightly more failures, especially under dry climate condition. Strategy 1 (dredging retention storage at Nong Yai) and Strategy 2 (use of groundwater) produce less failure ratios for the industrial sector, suggesting that these strategies are appropriate (or robust) under a broad range of uncertainties.

Irrigation sector

The acceptable threshold of strategy failure ratio was set at 20 percent, which is higher than domestic and industrial sectors. Figure 12.10 (Appendix) shows the performance matrix for the irrigation sector for C04, C06 and C07 sub-basin under climate and land-use change uncertainties for different water management strategies. Under all climate conditions and different land-use change scenarios, all four water management strategies including the business-as-usual scenario (no implementation of water strategies) perform well in sub-basin C04 and C06. Strategy 2 (using groundwater as an alternative water supply for small-scale irrigation) produces least failures compared with other strategies, suggesting that Strategy 2 is suitable (or robust) in addressing uncertainties in sub-basins C04 and C06. However, sub-basin C07 seems to suffer from a irrigation water deficit and all the identified water management strategies are not likely to alleviate a drought there (a high failure ratio above the acceptable threshold). The highest irrigation water shortage (a higher failure ratio) is seen during the dry climate scenario. As all land-use change scenarios produce an acceptable failure ratio in C04 and C06, changing from sugarcane to rubber in the upper region, and rice to sugarcane in the middle region seems to be appropriate for the irrigation sector.

Environmental sector

Even with a high acceptable failure ratio threshold of 20 percent, the Huai Sai Bat system fails to produce the required minimum discharge of 0.27 m^3/s in upstream of the basin, 0.6m^3/s in middle stream, and 0.77m^3/s in downstream as an environmental flow fig. 12.11, Appendix. The largest impacts are observed in the upstream and downstream sections of the basin during the dry climate scenario under an unchanged land-use scenario and an expansion of irrigation downstream. The failure ratio becomes worse when implementing the shifting of the crop calendar strategy, irrespective of any change in land-use. This insufficient flow in the river during the dry seasons may have adverse effects on aquatic animals and ecosystem services. However, land-use change scenario 2 (changing from sugarcane to rubber in the upper region and rice to sugarcane in the middle portion of the basin) requires less water than the business-as-usual approach in the upstream, so that more water is available for environmental flows. The adverse impacts of a minimum flow in the river are fewer under wet climate conditions.

Conclusions and recommendations

The Huay Sai Bat River Basin suffers periodic water scarcity given the increasing demands from an expanding agricultural sector. The drought in 2015 was considered critical due to its impacts on different sectors, including domestic water demand. Drought periods are exacerbated with uncertain climate variability, that include a delayed onset of the monsoon and prolonged dry spells during the wet season. State agencies in collaboration with local authorities have proposed selective strategies to alleviate projected droughts in Huy Sai Bat River Basin. They have prioritized water scarcity management strategies in this order: first, dredging the existing Nong Yai swamp to increase its water retention capacity; second, using groundwater as an alternative water supply; third, shifting the crop calendar; and fourth, constructing small cascade weirs along the river in the upper basin.

The RDS framework assessed the performance of all these strategies under a wide range of uncertainties due to changes in climate and land-use. WEAP was then used to simulate the water cycle of the river basin when the interventions from the aforementioned strategies were implemented. The performance of the proposed water management strategies were evaluated for four sectors (domestic, agricultural, industrial and environmental) by using water coverage (the percentage of water demand satisfied) and minimum river discharge. The findings from the performance evaluation are summarized below:

- Dredging the existing Nong Yai swamp to increase storage capacity could partially help to alleviate drought situations in sub-basin C01 (Kranuan district).
- Using groundwater as an alternative water supply for small-scale irrigation is an effective strategy for sub-basin C04 (Samsoong district) and sub-basin C06 (Cheunchom district).
- Delaying rice planting for one month is effective only for the rice farming areas outside the irrigation-serviced areas, while shifting the crop calendar could have negative impacts in irrigated areas.
- Building cascade weirs upstream could help to improve water scarcity situations in that part of the basin as weirs will be able to function as a small-scale water supply source.

During the consultation meetings and workshops, the project team received valuable recommendations from experts and representatives from relevant agencies. These recommendations included the following:

- Further analysis is necessary before providing recommendations for appropriate strategies. For example, constraints associated with saline groundwater should be considered in the modelling system for strategy 2 (using groundwater as an additional water supply). These constraints could have significant impacts, such as limiting groundwater usage for small-scale irrigation purposes.
- At the local level, it will be necessary to have effective engagement with the Huay Sai Bat River Basin Committee and other relevant agencies to support water resources management to prioritize the strategies and increase awareness among the river basin planners on addressing uncertainties and incorporating this knowledge into water resources management and planning.

- Trade-off analysis to investigate the economic and social impacts on the implementation of the robust strategies is also crucial for the decision-making process.
- Mainstreaming gender into development planning is necessary to ensure gender equality and women's empowerment. This approach is not limited to only inviting female participants to engage with the implementation processes, but it also recommends that gender topics should be discussed in the planning processes.

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Note

1 Unmet demand is the difference between the demand values in each demand node, and the amount of allocated water according to water availability and demand priorities. If water supply is insufficient, there will be unmet demand.

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13

Addressing urban water scarcity in Can Tho City amidst climate uncertainty and urbanization

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Can Tho City, located in Vietnam's Mekong River Delta (MRD), is one of the biggest and fastest-developing cities in southern Vietnam. Water management in the city is a complex undertaking that faces a number of constraints: increasing urbanization, rapid population growth, inadequate infrastructure development, and inefficiencies in management. Combined with these, an increase in demand for domestic water, water pollution, seasonal inundation, and the scarcity of clean water pose huge water management challenges for the city. These issues have added a layer of uncertainty in terms of both temporal scale and change magnitudes from climate change and rising sea levels. To address these challenges, the city requires not only appropriate short-term adaptation measures, but also policies and strategies for long-term urban water management.

This chapter presents findings from a year-long study that aimed to: identify key stakeholders and tools to support the decision-making process for urban water management; build a complete multi-agent model to evaluate present and future scenarios; and engage with stakeholders to ensure the developed model's results are taken up and used in future decisions.

The study uses system dynamics i.e. methodologies to frame, understand, and discuss complex issues and problems. Through a multi-agent modeling exercise, which was built on a combination of the Storm Water Management Model (SWMM) (flood simulation model) and VENSIM (water quality simulation model), a number of short-term and long-term policies and strategies were produced to address water insecurity in Can Tho City. These proposed measures were prioritized by the key stakehoders as: upgrading retention reservoirs, upgrading the existing drainage system, increasing the permeable area, water conservation, and household wastewater treatment.

Can Tho City is the urban center of the Mekong Delta in Vietnam. Water is central to everyday life and underpins the local economy, including agriculture, aquaculture, transport, and tourism. Table 13.1 shows how this natural resource is currently under pressure from increasing urbanization and climate change and sea level rise (Can Tho University 2009). Rapid economic development combined with population growth have placed enormous pressure on the city's water supply, especially potable water for household use, services and manufacturing. In addition, investments in water-related infrastructure for supply and sanitation have not kept pace with rapid urbanization, particularly in the peri-urban areas (Herbst et al. 2009).

The Mekong Delta has a tropical moonsoon climate with distinct wet and dry seasons. In the dry season, flows from the upstream Mekong River decline. Along with rising sea levels, this results in saline water intrusion into surface waterways. Groundwater is one of the possible options for the city to meet its potable water demands (Danh 2008). However, the over-exploitation and the pollution of groundwater has already resulted in a decline in both water storage quantity and quality (Neumann et al. 2011; Moglia et al. 2012; Erba et al. 2014). Excessive groundwater pumping has also resulted in land subsidence of 1 to 2 cm/year in many areas (Erban et al. 2014).

Study area

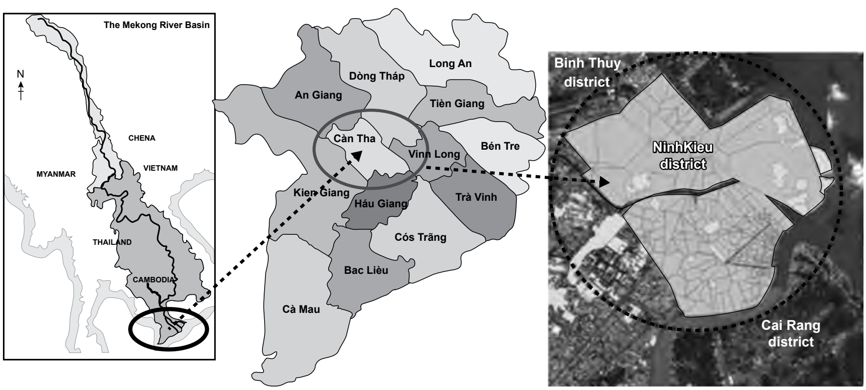
Can Tho City is the biggest city in the Vietnamese Mekong Delta, with an altitude of about 1 m above mean sea level. The city has nine districts (four urban districts and five rural districts) with a total area of about 1,400 km^2. The city has a population of about 1.2 million, a figure which is expected to grow to 2.1 million by 2030, with about 52 percent of the population living in core urban districts. Its population density is about 870 people/km^2. Rapid urbanization and population growth is placing greater pressure on the city's current infrastructure. The majority of urban livelihoods in Can Tho, including agriculture, fishing/aquaculture, services, and goods manufacturing, depend largely on water.

Table 13.1 Main impacts of climate change on water resources in Can Tho City

Factor	Issues
Water quality	Water quality will be most impacted by climate change. Both surface and groundwater quality are degraded as pollutants are not diluted or flushed out to sea because of a weakening upstream flow (due to dam constructions). Increasing saline intrusion will influence both surface and ground water.
Water and sanitation	Positive effect during rainy season is to provide 'cleaner' water sources; however, during dry season, there is a shortage of potable water (even in households with tap water). Due to these shortages and other likely negative effects on the water resources, including water quality of the river as well as the decrease in discharge in dry season affected by upstream dam projects, access to water will be reduced for households as well as for industry and agriculture. Climate change will impact water and sanitation access, given more pronounced dry/wet seasons, especially for those who use water directly from rivers (Moglia et al. 2010).
Groundwater	Freshwater shortages will lead to the pumping of groundwater in Can Tho. Given higher temperatures and increased sea level, the volume and the quality of groundwater will be affected by higher extraction rates, higher evaporation rates, increased tidal effects, and salinity intrusion. Groundwater will be less directly and more slowly impacted by climate change, as compared to e.g. rivers. Rivers are replenished more quickly, in a shorter time scale, and drought and floods are quickly reflected in river water levels. However, after prolonged droughts, groundwater levels will show declining trends (Moglia et al. 2010).
Flooding	Regarding sea level rise scenarios, flooding and tidal levels in the urban area will become more severe. Moreover, over-exploitation of groundwater results in soil subsidence, increasing flood levels (Konings 2012; Erban et al. 2014). Flood damage will vary and be costly because of low-lying and high density buildings and street-level activities. Old flood protection measures such as dikes and sluice gate systems will malfunction since the floodwater levels will be higher than the old benchmarks. New flood protection measures will be costly given Can Tho City's low terrain (0.3-2 m).
Infrastructure	Infrastructure (especially water supply infrastructure) will be affected and damaged by more severe conditions, including flood events, placing greater pressure on infrastructure. In Can Tho City, the current water management policies and practices are inadequate for reducing demand on water resources and mitigating the severity of other water-related problems (Moglia et al. 2010).

Ninh Kieu district, the most-developed and important district in Can Tho City, with 209,274 people and 29.22 km^2 in extent, was selected as the main study site (fig. 13.1). With rapid socioeconomic development, a growing population and urbanization, this district is also representative of the city as a whole, facing flooding in the wet season, and a shortage of water in the dry season as well as water pollution. All these existing problems look set to be exacerbated under climate change and rising sea levels in the future.

Figure 13.1. Location of Can Tho City (left and middle) in the Mekong Delta in Vietnam. Ninh Kieu district (right) in the study site.



Study objectives

Can Tho City needs appropriate and effective policies and strategies on water management to address the decline in water quality, low access to potable water and poor sanitation, declining groundwater levels, increased risk of flooding, and inadequate water infrastructure.

This study attempts to develop an integrated approach to addressing the water management challenges of Can Tho City in the context of climate change, rapid population growth and economic development. The specific objectives of this study are:

- To ensure stakeholder engagement in urban water management;
- To develop suitable analysical tools/models to define the water scenarios and evaluate the effectiveness of the potential measures;
- To propose appropriate measures for urban water management; and,
- To build collaborative stakeholder networks based on mutual understanding and trust.

Methodology

The study uses the Robust Decision Support (RDS), an approach that is based on theoretical decision-making under an uncertainty framework referred to as the Robust Decision Making (RDM) framework (Lempert et al. 2003). After identifying the stakeholders concerned with urban water scarcity in Can Tho, the study team applied the "XLRM problem formulation framework" to describe the decision space with four groups of elements (Lempert et al. 2003):

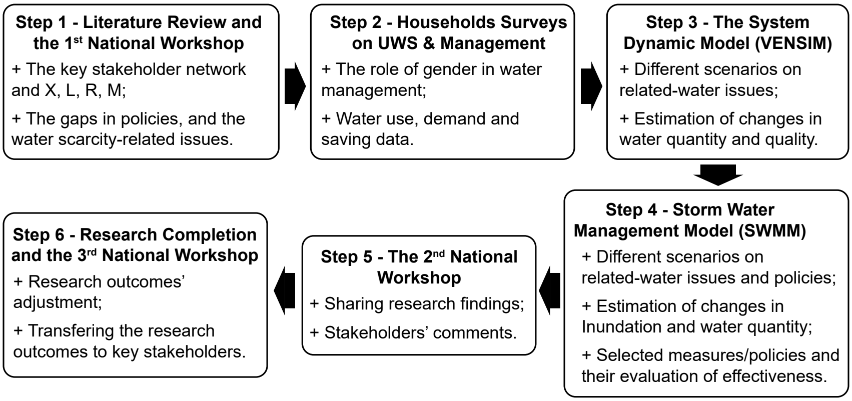
(i) Policy levers ("L") are near-term actions that, in various combinations, comprise the strategies decision-makers want to explore;
(ii) Exogenous uncertainties ("X") are factors, outside the control of the decision-makers, which may nonetheless prove important in determining the success of their strategies. In the language of scenario planning, the Xs help determine the key driving forces that confront decision-makers;
(iii) Measures ("M") are the performance standards that decision-makers and other interested communities would use to rank the desirability of various scenarios; and
(iv) Relationships ("R") describe the ways in which the factors relate to one another and so govern how the future may evolve over time, based on the chosen decisions and the manifestation of the uncertainties.

Figure 13.2 provides a synopsis of the methods and tools applied during this one-year study from June 2015 to June 2016.

The following main steps, modes/tools and methods were undertaken and used to achieve the case study's objectives:

- *Step 1: Literature review and the 1st national workshop.* Based on the RDS framework, this step aimed at (i) ascertaining the main water scarcity-related issues in Can Tho City (floods and water pollution); (ii) identifying and consulting stakeholders on current policies and strategies as well as gaps related to the city's urban water management; and (iii) recognizing exogenous uncertainties (X) both in socioeconomic and natural changes, proposing potential inundation and pollution control measures (L), defining indicators to evaluate the measures' effectiveness (M), delineating the relationships (R) among X-L-M,

Figure 13.2 Study methodology



and (iv) building a stakeholder network in the city's urban water management to prepare for the development of databases and selected appropriate models, including the Storm Water Management Model (SWMM), which was developed by the United States Environmental Protection Agency (EPA) (USEPA 2016), and the System Dynamic Model (VENSIM), developed by Ventana Systems (Ventana Systems 2016) to support decision-making processes. Several methods, water models and tools were applied in this step including workshops, focus group discussions, stakeholder mapping, and interviews.

- *Step 2: Household survey*. A survey of 200 households was conducted to understand the perceptions of the local community about water demands and their views on future water issues, especially the role of women in saving water. The survey results were used as inputs for the VENSIM and SWMM models (fig. 13.3).
- Step 3: The System Dynamic Model. The VENSIM system dynamic model was used to project the changes in wastewater quality and quantity in each drainage sub-catchment of the study area. The projected scenarios were defined based on different time scales (present and future) according to related socioeconomic scenarios (population growth, economic development plans, water demand, etc.). These outputs were used as inputs for Step 4. Due to time and budget limitations, this study only projected the chemical oxygen demand (COD) level for wastewater quality. The model projected the

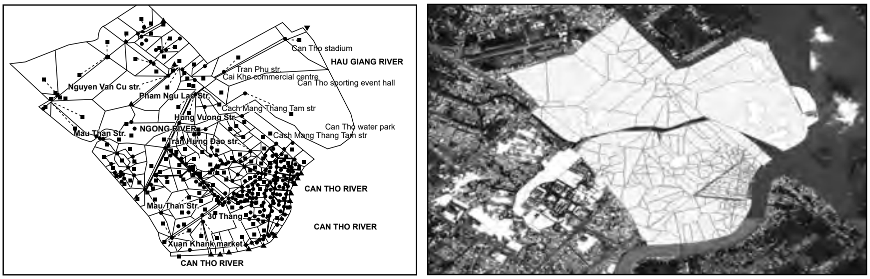
Figure 13.3. Survey on role of gender in household water use, Can Tho City

total wastewater quantity and quality of the case study from a number of key sub-models namely, households, hospital, markets, offices and industry. Data used for the model were collected from the survey and a review of research reports, statistical yearbooks, government documents, and websites.

- *Step 4: The Storm Water Management Model (SWMM)*. An existing SWMM (EPA 2015) developed for Ninh Kieu district by Huong and Pathirana (2013) was used to project and evaluate indicators (M) related to the inundation (including the flood point, volume, duration and level) and water quality (COD concentration) in the drainage network under different alternatives of adaptation (fig. 13.4).

  Three adaptation scenarios were considered based on the water demand and water saving, wastewater treatment, population and socioeconomic growth, and rainfall and tide data. The model inputs included (i) water quality (COD level) and wastewater quantity from the VENSIM model (Step 3), (ii) rainfall and tide data, and (iii) reservoir and permeable areas. Based on the built scenarios and the findings of Step 1, appropriate policies and strategies for reducing flooding, enhancing water drainage capacity, improving water quality and preventing potable water scarcity issues were assessed and compared for effectiveness as well as investment cost.
- *Step 5: The 2nd national workshop.* This workshop focused on sharing key results and information gathered to date, consulting and receiving comments and feedback on these results from stakeholders, helping to improve their knowledge, and sharing experiences as well as perceptions about urban water scarcity-related issues for

Figure 13.4. The water permeable area (left) used in the SWMM; the water drainage and supply network (right) in the study site



the local stakeholders. The workshop included participation from representatives of government, NGOs, local associations, academics and the private sector with focus group discussions, professional knowledge exchange and sharing of research findings. All comments and feedback collected in the workshop were extensively discussed and used to verify and help improve the research findings. The models and tools used at the workshop included presentations, focus group discussions, questionnaires and interviews.

- *Step 6: Research completion and 3rd national workshop*. From comments and feedback collected from the 2nd workshop, research outcomes were adjusted and reflected in the study reports, book chapter and policy briefs that were developed. In the 3rd national workshop, the final research outcomes and main products (e.g., models, books, journals, etc.) were shared and transferred to key stakeholders and boundary partners (tables 13.11, 13.12) through meetings, training, email, letters, and a website to ensure the adoption of the project's outcomes.

Results and discussion

Key uncertainties (X), levers (L), metrics (M), and relationships (R)

The 1st national workshop was organized with the aim of identifying the key stakeholders who shared knowledge and experiences to identify uncertainty factors (X) and appropriate measures (L) for solutions to the city's potable water scarcity.

As the result, the workshop developed a list of exogenous uncertainty factors (X) relating to the city's water scarcity management that included both socioeconomic and natural-environmental factors (table 13.1). In terms of the socioeconomic aspect, the city's water demands would increase due to population growth (both from the natural population and migration) together with uncontrolled urbanization and industrial development. In terms of the natural-environmental factors, the impacts of climate change were considered as the most significant uncertainty. Climate change could cause unexpected floods due to intense rainfall in the wet season in the city and brings the risk of significant damage to houses, infrastructure as well as changes in water quality. In the dry season, the effect of sea water (saline) intrusion would become more serious due to decreasing water discharged into the Mekong River upstream, in particular when salinity is combined with a lack of proper wastewater treatment for hospitals, offices, markets, households, and industries. The uncontrolled exploitation of groundwater as a response to water pollution, as one of the options to meet the city's expanding water needs, would result in further land subsidence and, as a consequence, more inundation in the city. In summary, inundation and water pollution are two of the main factors causing water scarcity in urban areas in the near future.

During the workshop, participants also discussed and identified potential measures (L) that could resolve or reduce the city's vulnerabilities relating to inundation and water pollution (table 13.3). These measures were divided into structural measures (L_s) and non-structural measures (L_n). The structural measures include improving water storage (reservoirs), upgrading drainage capacity, and increasing the permeable area; and the non-structural measures include encouraging water saving and improving household wastewater treatment by installing septic tanks, which are very small-scale distribution wastewater treatment systems with low investment cost.

Table 13.2. Key uncertainties in water scarcity management, in Can Tho City

External Factors (X)		
Key X-Factor	**Trend / Degree of Uncertainty**	**Information**
Water demand increasing - Urbanization (commercial development, physically population increasing and immigrants) - Industrial development	- Increasing	PC, PCO, DOC, DONRE, DPI, IOES, Statistics Department, Department of Industrial Zones Management, Department of Industry and Commercialization, Can Tho City's Public Security
Flooding - Land subsidence - Extreme local rainfall - Upstream flows - Tide (salinity intrusion and water level rise)	- Increasing - Increasing in rainy season and decreasing in dry season - Complexity (Increasing in rainy season and decreasing in dry season) - Increasing	DONRE, MONRE, Mekong River Committee (MRC), CCCO, Southern meteorology station, Can Tho meteorology station, National meteorology center
Water pollution	- Increasing	DONRE, MONRE, MRC, DOC, DOST, WSSC, CEFWS

The performance of measures and thresholds (metrics: M) used to evaluate the effectiveness of the measures were also determined by the workshop participants (table 13.4). The flood point, volume (m^3), duration (min) and level (m) were thresholds used to evaluate the performance of measures during an inundation. COD concentration was calculated and compared with the official water quality standards in Vietnam. The effectiveness of water-saving measures was evaluated by domestic water demand indicators (liter/person/day).

Stakeholders also determined the cause-and-effect relationships among the uncertainty factors (X), proposed measures (L) and metrics (M) to evaluate the efficacy of the proposed measures (L). Each relationship (R) was proposed with respect to all the other factors. Similarly, a further determining factor was identified by the stakeholders and more connections established. The relationships among the factors in the model are presented in fig. 13.5. In the figure, the continuous and dotted lines from X show the consequences of X to the city's water-related problems

Table 13.3. Key levers for potable water scarcity management in Can Tho City

Levers (L)		
Strategies	**Influence**	**Information**
Increasing water storage and drainage capacity - Water regulation storage (building/upgrading storage lakes, retention reservoir) - Improving urban water drainage system/network	- Increasing water storage capacity and ability to control water - Ensuring quantity of water - Regulating water flows - Reducing the risk of both water scarcity and flooding	DONRE, MONRE, DARD, DOC, DPI, urban project companies, WSSC, DOST, DOIC
Improving urban and residential area planning, and water resources planning - Increasing permeable area - Creating greater green spaces	- Increasing water absorption - Decreasing water pollution and mitigating saline intrusion - Increasing water quantity - Controlling and decreasing population density	PC, PCO, DOC, DONRE, DPI, DOF, DOIC, DOLISA, associations and unions
Water treatment plant - Building centralized and decentralized wastewater treatment plants	- Improving water quality and human health protection - Decreasing deterioration ensuring sanitation; reducing water leakage and saving water	MONRE, DONRE, DOC, DPI, WSSC, WSSC, IPMBs, DOM, DARD
Information and communication - Improving awareness - Increasing water saving - Increasing dissemination activities	- Enhancing human awareness for effective water use - Improving human health - Mitigating negative activities for urban water and protecting water resources - Decreasing water pollution	PC, PCO, DOIC, DOET, related associations and unions

Table 13.4. Key metrics used to evaluate effectiveness of proposed measures

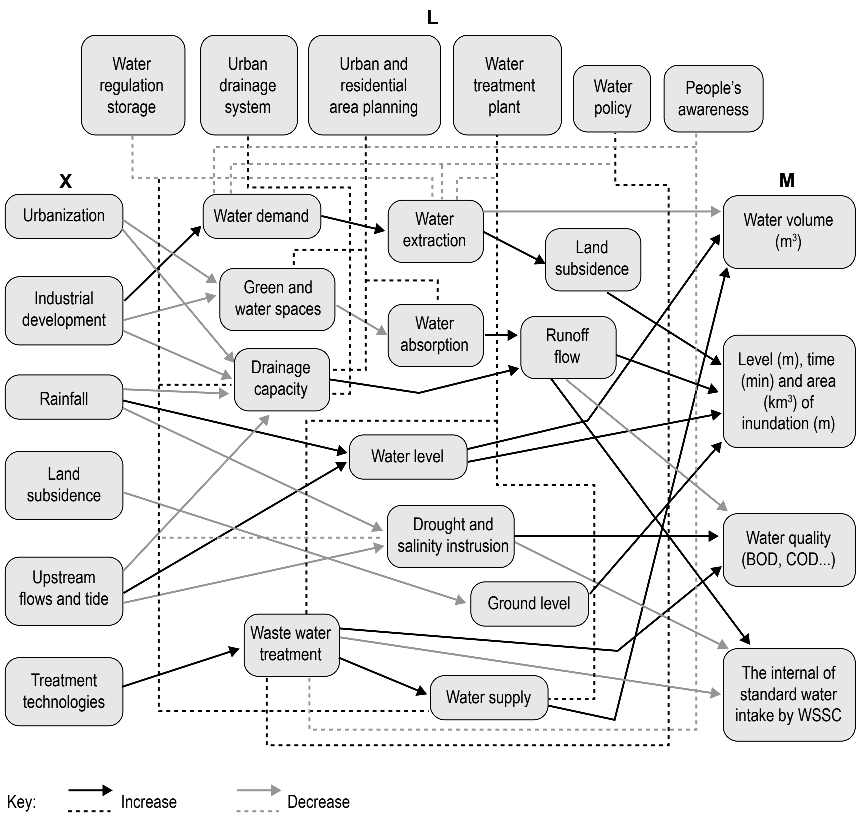
Metrics (M)		
Indicators	Thresholds/levels	Information
Surface water quantity	Domestic use: 150 L/person/day	DONRE, WSSC, CEFWS, DOC, DARD
Surface water quality (COD concentration)	- Domestic using water standard (TCVN 02-01) - Drinking water standard (QCVN 01/2009-BYT) - Surface water for ecology (TCVN 08/2008) - Percentage of clean water accessed in urban area (100 percent)	MONRE, DONRE, WSSC, CEFWS, DOM, DARD
Reduced flooding point, volume, duration and level	Point, volume (m^3), duration (min) and height (m). To be defined based on baseline data	MONRE DONRE, DOC, DARD, urban project companies, MRC, CCCO, Southern meteorology station, Can Tho meteorology station, National meteorology center

(white boxes). The continuous and dotted lines from L to white boxes show the problems that L will affect (fig. 13.5). Generally, drainage capacity, water collection spaces (e.g. reservoirs, permeable areas) and wastewater treatment appear to have multiple relationships with X, L, M and other R. If these issues can be solved, deterioration of water sources will decrease and available water sources for hospital, office, domestic, commercial and industrial uses will increase.

Household survey on gender in water use and management

The survey gathered information on and evaluated the role of gender in households' water use and management, which provided data for building the VENSIM and SWMM models. The number of households surveyed was based on Slovin's formula (1984), which includes the total number of households and permissible errors (7.15 percent). Through discussions with local experts in well-established, older urban areas, newly built urban areas, and peri-urban wards, the 200 households

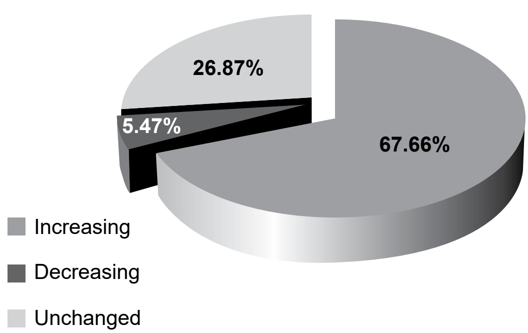
Figure 13.5. The key relationships for potable water scarcity management in Can Tho City. The continuous lines from X show the consequences of X to the city's water-related problems. Dotted lines from L to boxes show which problems that L will impact on.



surveyed (out of nearly 173,000 households in the study area) were randomly selected and divided into groups of water users, including domestic water users, businesses/manufacturing (small restaurants, coffee shops, bottled water plants, etc.), and services (rented houses, car washing, etc.). This grouping was used to structure the analysis of the survey results to understand householders' perceptions of water use, water demand and water saving. The following are the key results that emerged from the survey:

- All households can access potable water. Tap water is the main water source for daily activities such as cooking, washing, sanitation, etc., in all surveyed households. Businesses/manufacturers and services (nearly 25 percent of surveyed households) also use tap water for their operations. In the wet season, a few households also use rainwater for gardening, washing and toilets.
- Over 40 percent of interviewees stated that there were several problems relating to tap water quality, such as pungent or chlorine smells, yellow and muddy water. These problems are mainly due to the washing of water tanks by the city's Water Supply and Sewerage Company (WSSC), water disinfection and the repair of water pipes.
- Monthly water use per person in the city was 4.51 m^3 (around 150 liters/day). Figure 13.6 shows that 68 percent of interviewees said that their household water demand is increasing due to increasing temperatures (water used for showers and washing), population growth (more water used in washing machines etc). However, over 70 percent of households have applied water-saving solutions to daily activities. Some of these households only apply water savings in the dry season. The majority of interviewees are aware and have knowledge of water saving with the average potential monthly water saved per person in the order of 0.6 m^3 (around 20 l/day).

Figure 13.6. Expected changes in future water demand of households (%)



- According to the results of the survey, women have a dominant role in decision-making related to water use and management in households. Women have a higher level of water demand and use (fig. 13.7) because they do most of the housework and are also responsible for the small family businesses and have a greater interest in and understanding of water-related issues. Compared with men, a greater number of women attend community meetings related to water or environmental issues. As women are responsible for the payment of monthly water bills, they have a greater motivation to apply water-saving techniques (fig. 13.8).

Figure 13.7. Water use and demand by gender (%)

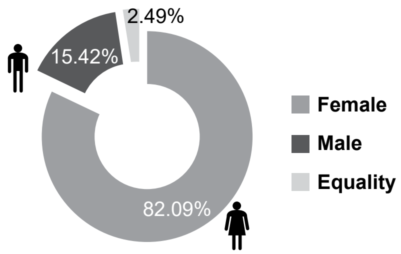
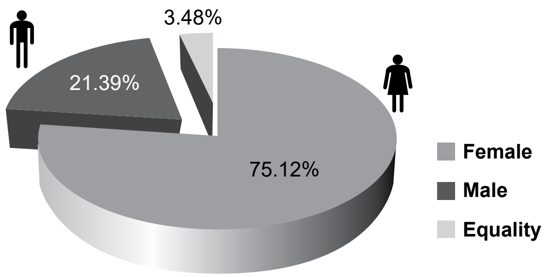
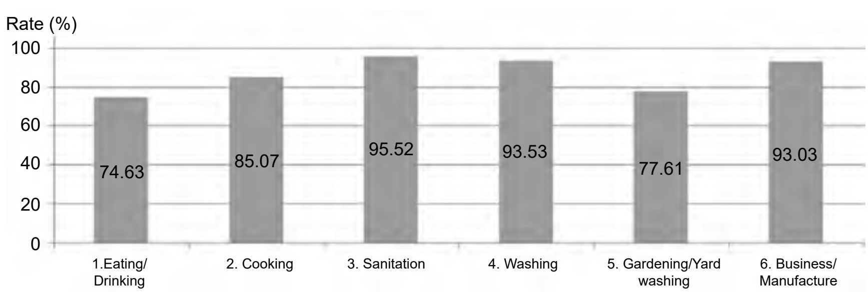


Figure 13.8. Gender in household water use decision-making (%)



- Drinking, cooking and personal sanitation are the priority water use in households, followed by washing, gardening, running a business and manufacturing (fig. 13.9).

Figure 13.9. Household water use profile (%)



The survey findings were used in making water-saving scenarios in the VENSIM and SWMM models and support the city's water management decision-making.

Models and scenarios for RDS application in the case study

VENSIM was used to project changes in water quality and wastewater quantity in each sub-catchment under present and future scenarios, given changes in policies, water demand, population growth and socioeconomic development. The VENSIM outputs were then used as inputs for the SWMM. The SWMM projected the scale of inundation and water quality in the drainage network under present and future scenarios, with different adaptation activities and policies related to water demand and saving; wastewater treatment; and population and socioeconomic growth.

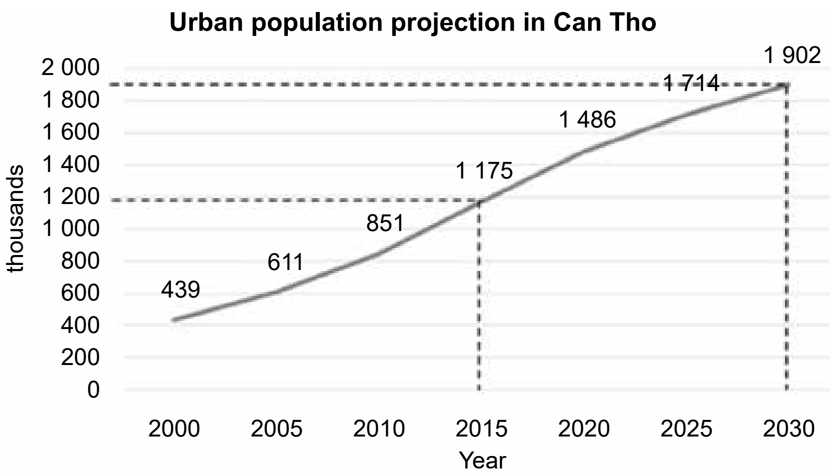
Table 13.5 presents the key uncertainties/external factors (X) and levers/measures (L) selected to denote the signs and description of the scenarios used in the VENSIM and SWMM models to simulate changes in water quality and inundation status, and assess and compare effectiveness and investment costs under present and future scenarios.

Table 13.5. Key uncertainties/external factors (X) and levers/measures (L) for scenario assessment

Uncertainties/External Factors (X)	Levers/Measures (L)
Socioeconomic uncertainties	Structural levers
X_e0: Development as current situation (base scenario)	L_s0: No action
X_e1: Development as planned	L_s1: Increasing permeable area
X_e2: High development (10 percent)	L_s2: Upgrading reservoir
Natural uncertainties	Ls3: Upgrading drainage system
X_n0: Rainfall and tide in 2015	Non-structural levers
X_n1: Rainfall and tide in 2030	L_n1: Water saving
	L_n2: On-site wastewater treatment (septic tanks)

The projected scenarios were defined based on different time scales (present and future) and the city's socioeconomic scenarios. These scenarios were defined based on the population and economic growth statistics, such as the current growth rate (2004–14), the target growth rate according to the Decision on Socioeconomic Development Plan of Can Tho City to 2020 and Vision to 2030 by the Prime Minister of Vietnam in 2013, and a faster growth rate scenario (target growth rate + 10 percent). The city's predicted population growth up to 2030 is shown in fig. 13.10.

Figure 13.10. Projected population growth of Can Tho City in 2030 (UNDESA 2014)



Results from the VENSIM model

The changes in water quality (COD level and load) and wastewater quantity (volume) in the study area's drainage system are simulated in six different scenarios related to population and socioeconomic development (S), changes in water use and demand, and changes in water policies.

Table 13.6 shows six scenarios used in the VENSIM model. The boxes with ticks in the table represent each scenario's selected cases relating to population growth, socioeconomic development, water demand and policy changes.

Table 13.6. Six scenarios used in the VENSIM model

		Characteristics										
Scenario Description		Population Growth		Socioeconomic/Urban Development			Water Demand (liters/capita/day)				Wastewater Treatment	
		As predicted in 2030	10% higher than the city's prediction in 2030	Current situation	As planned in 2030	10% higher than the city's planning in 2030	Current situation (150 liters)	As predicted in 2030 (180 liters)	22% higher than the city's prediction in 2030 (220 liters)	Reducing water consumption as holistic policy	Not treated	Treated by household septic tanks
X_e0	Development as current situation (based scenario)	✓		✓			✓				✓	
$X_e0.$ L_n2	Base scenario + treated wastewater	✓		✓			✓					✓
X_e1	Development as planned	✓			✓			✓			✓	
$X_e1.$ L_n1	Development as planned + water saving	✓			✓					✓	✓	
X_e2	Higher development		✓			✓			✓		✓	
$X_e2.$ L_n1	Higher development + water saving		✓			✓				✓	✓	

Note: Marked boxes represent the characteristics taken into account for each scenario.

- Scenario 1 – **X_e0**: Development as current situation (based scenario);
- Scenario 2 – **X_e0.L_n2**: Base scenario + on-site wastewater treatment by household septic tanks;
- Scenario 3 – **X_e1**: Development as planned;
- Scenario 4 – **X_e1.L_n1**: Development as planned + water saving;
- Scenario 5 – **X_e2**: Higher development;
- Scenario 6 – **X_e2.L_n1**: Higher development + water saving.

Figure 13.11 illustrates a part of the developed VENSIM model. Wastewater in the study area is classified into a number of key categories that are based upon its source, namely domestic, markets, hospitals, offices/schools and industry. The model visually highlights the large number of water use-related factors, sectors and purposes as well as the multiple relationships between them.'

In the case of predicted population growth in 2030 and socioeconomic development as of 2015 (X_e0), as shown by figs. 13.12 and 13.13, the volume of wastewater generated in the study area is about 8 million m^3/year, and the total COD load of this volume is estimated to be 1,451,330 kg. However, for X_e0 scenarios, if wastewater is primarily treated by households' septic tanks before being discharged (X_e0.L_n2), the volume of wastewater would not be reduced, but the COD load would be cut by approximately 30 percent in 2030.

In the case of predicted population growth by 2030 and socioeconomic development growth as planned over the same period (X_e1), the wastewater volume and COD load discharging into drainage network increases to 10,246,800 m^3/year and 1,737,380 kg respectively. However, if households could save water (X_e1.L_n1), both the volume of wastewater and COD load would decline by 5,406,030 m^3/year and 1,108,080 kg, respectively.

By 2030, in case the city's population increases faster than predicted (by 10 percent) and the socioeconomic growth is 10 percent greater than planned (X_e2), the quantity and COD load of wastewater discharged will be double that of the current development scenario (X_e0). However, in the scenario where development is 10 percent faster than planned (X_e2), if households apply water-saving practices (X_e2.L_n1) with an overall water use of 90 liters/capita/day, the wastewater volume, and the COD load will decline by 54 percent and 42 percent respectively, compared to scenario X_e2.

Figure 13.11. Estimated changes in water quality and wastewater quantity in study site (VENSIM)

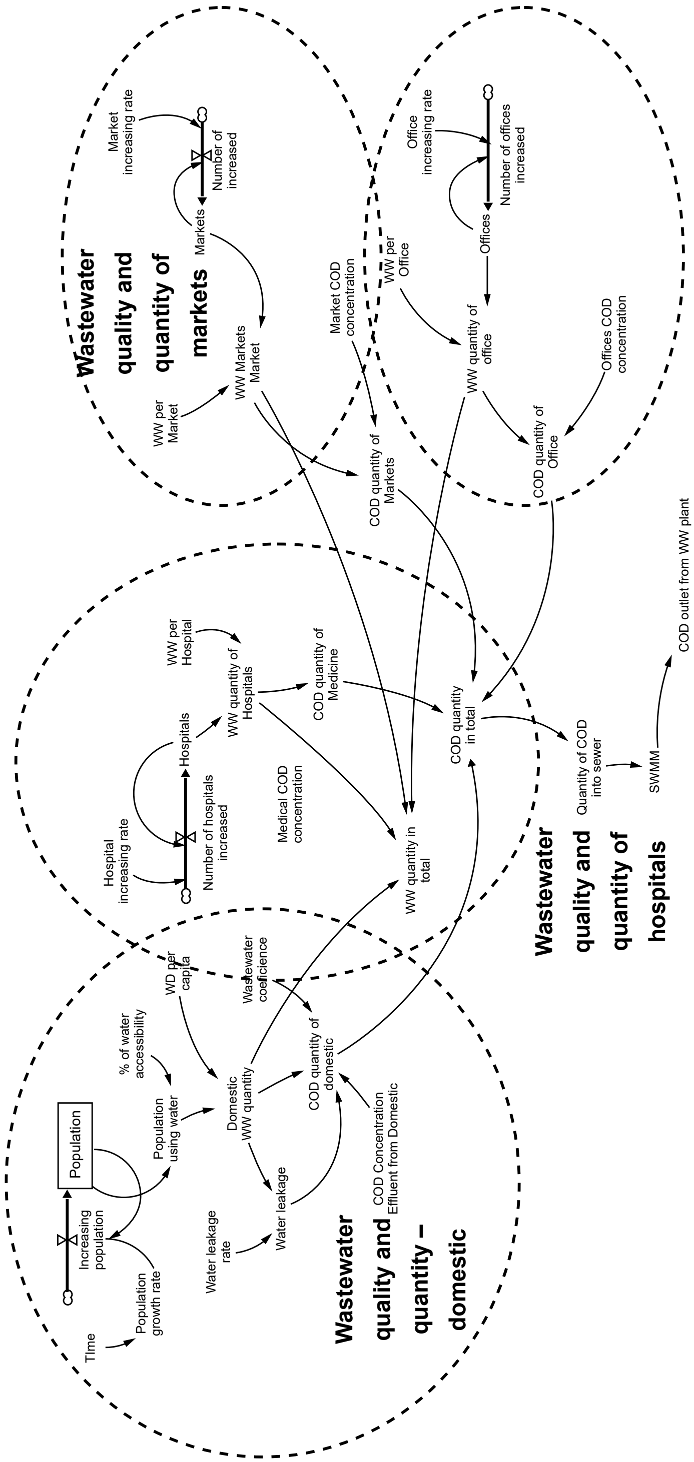


Figure 13.12. Changes in wastewater (WW) quantity and COD load under the six scenarios in the study area's water drainage network from present to 2030

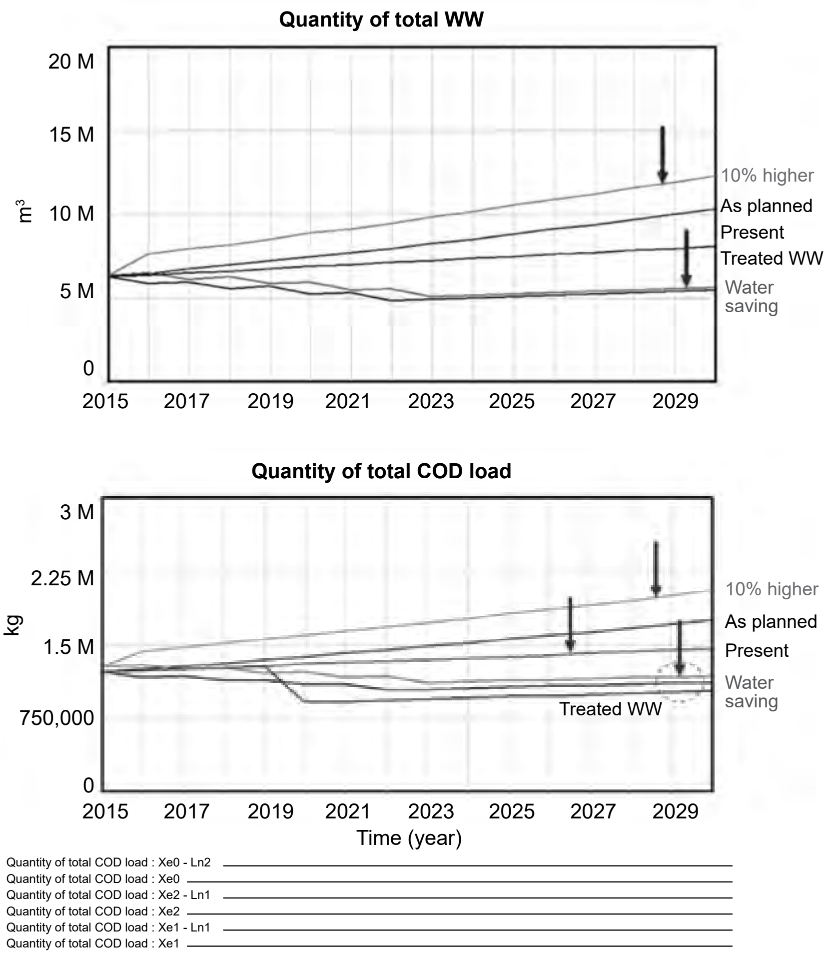
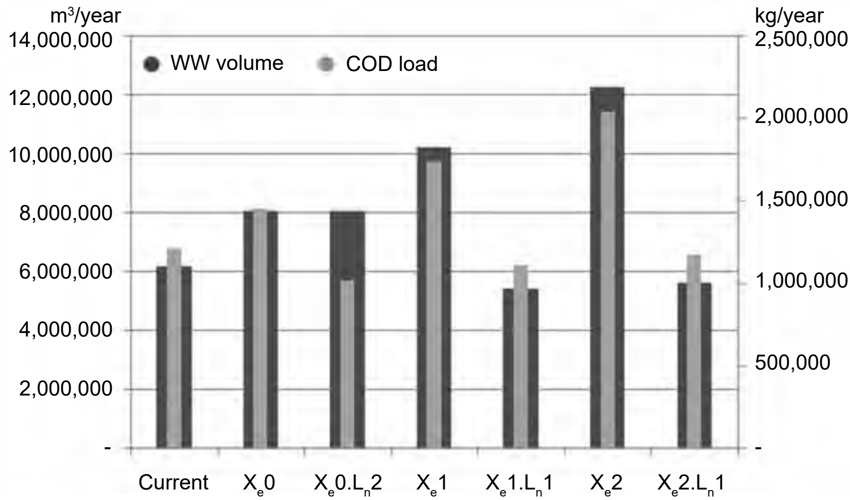
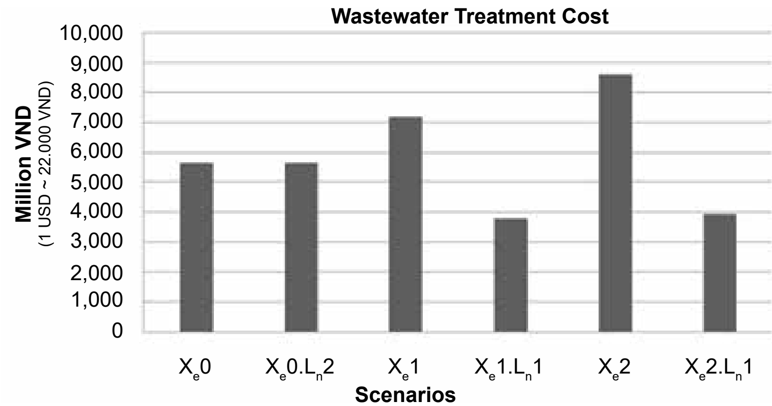


Figure 13.13. Changes in wastewater quantity and COD load under the six scenarios in the study area's water drainage network in 2030



In terms of the wastewater treatment cost (fig. 13.14), and assuming a 0.03 US$/m^3 (PCCTC 2017), the cost of treatment for the whole region is approximately US$320,000 /year. This is based on the assumption that economic growth is in line as planned by the city. If economic growth is 10 percent higher than planned, the annual cost of wastewater treatment would increase to nearly US$390,000. However, with the implementation of water-saving measures, the cost would decline to US$180,000/yr (about 50 percent lower).

Figure 13.14. Wastewater treatment costs under the six present and future scenarios in the study area



Results from SWMM

To investigate flood mitigation in Can Tho City, the SWMM model was used to evaluate the effectiveness of structural measures, including increasing the total permeable area (L_s1) by 1 percent, upgrading retention reservoirs (L_s2), and upgrading one pipeline in the drainage system at a city's flooding hotspot (area from 30/4 street to Hoa Binh street) (L_s3). "No action" (L_s0) was used as baseline measure to compare with other measures' effectiveness. The model analyzed 28 different combined scenarios relating to population and socioeconomic factors (X) and climate change and sea level rise/tide scenarios (X_n0: Current rainfall and tide, X_n1: Projected rainfall and tide in 2030). Table 13.7 presents different present and future scenarios relating to population and socioeconomic development.

Table 13.7. Population growth and socioeconomic development scenarios (X) applied in the SWMM

Scenarios	Population growth		Socioeconomic development		
	Present (2015)	As predicted in 2030	Present (2015)	As planned in 2030	10% higher than the city's planning
X_e00	✓		✓		
X_e10		✓	✓		
X_e11		✓		✓	
X_e12		✓			✓

Note: Marked boxes represent the characteristics taken into account for each scenario.

The effectiveness and investment cost of measures were assessed and compared (tables 13.8, 13.9 and 13.10). Table 13.8 presents the effectiveness and investment needed for reducing floods and improving water quality in the present scenarios ($X_e00.X_n0$). The results show that an increase in 1 percent of the total permeable area (by upgrading the sidewalks) although it would not reduce the number of flooded points could help decrease the volume of floodwater. This measure is considered to be a good option for the city due to its low investment cost and high effectiveness (reducing flood water volume by nearly 60,000 m^3 or 1.2 percent).

If we increase the reservoir volume (L_s2), the flooding points and volumes are significantly reduced, while installing a new water drainage pipeline (L_s3) at the representative locations in the city (30/4 street to Hoa Binh street) reduces the flooding at the representative points completely (100 percent). However, the latter is unlikely to be efficient in other areas since the conditions for drainage such as the terrain (e.g. low elevation), infrastructure available (e.g. no riverbank dike) and the receiving drainage water (e.g. high water levels due to high tides) may not be favourable. In addition, the high level of investment required for this option should also be considered.

If population growth as predicted occurs, rainfall and tides are as projected for 2030, and socioeconomic development according to the 2015 plan ($X_e10.X_n1$) (table 13.9), upgrading the city's reservoirs (L_s2) can

Table 13.8. Effectiveness of measures and investment for reducing flooding and improving water quality in present scenarios (Xe00.Xn0)

Scenarios	Whole study area			At the representative point: 30/4 - Hoa Binh St		Whole study area
Population growth, socioeconomic development, rainfall and tide as 2015 ($X_e00.X_n0$)	Flooding		Water quality	Flooding		
	Point	Volume (m^3)	COD concentration (mg/l)	Time (hour)	Level (m)	Investment cost level
No action – L_s0	311	634,948	206	1.75	0.41	-
Increasing permeable area (~1% of the total study area) – L_s1	0%	1.2%	0%	0.6%	0%	Very low
Upgrading reservoir – L_s2	3.5%	5%	0%	0%	0%	Medium
Upgrading drainage system (a new water drainage pipeline) – L_s3				100%	100%	Very high

Robust	0%		100%
Not robust	0%		-100%

decrease flood issues (reducing 3.4 percent of flooded areas, 9.1 percent of flood volume, 11.5 percent of flood duration and 2.1 percent of flood level). Similarly, upgrading a water drainage pipeline has a positive effect on diminishing flood durations and levels (97 percent and 89.4 percent, respectively). Besides, water-saving measures (L_n1) are shown as effective in reducing the volume and duration of a flood (25.5 percent and 55.3 percent, respectively); with on-site wastewater treatment by septic tanks in households (L_n2) being the most effective measure for reducing water contamination (39.9 percent COD concentration). The water saving, and septic tanks, also have low investment options.

To increase the effectiveness of these measures, the combinations of structural and non-structural measures were assessed. As table 13.9

indicates, the combined measure of "upgrading the reservoir + water saving – $L_s2.L_n1$" is not only one of the most effective measures for reducing an inundation (4.3 percent of the area, 30.9 percent of the volume, 58.7 percent of the duration, and 4.3 percent of the level), but is also a medium-level investment. The combined measures in "upgrading of the drainage system – L_s3" are the most effective solution for decreasing flooding (over 97 percent of duration and 89.4 percent of water level). In terms of water quality, the combined measures "on-site wastewater treatment by septic tanks in households (L_n2)" are still the most feasible solutions (reducing around 40 percent of COD level in wastewater).

If Can Tho's population and economy grow 10 percent faster than the government prediction at the same time, and rainfall and tides are 10 percent higher than predicted for the 2030s ($X_e12.X_n1$), the model results show that the option of upgrading reservoirs (L_s2) has a positive effect (3.9 percent of flooded areas, 11.1 percent of flood volumes, 12.4 percent of flood duration and 3.9 percent of flood levels) for a medium-level cost. At the representative point (30/4 Hoa Binh street), the single or combined measures including "upgrading a new water drainage pipeline – L_s3" significantly decreased flood duration and level, over 97 percent and 88 percent, respectively. In terms of water quality, most of the single or combined measures such as on-site wastewater treatment (L_n2), increasing the permeable area+ on-site wastewater treatment– $L_s1.L_n2$, and upgrading the reservoirs + installing on-site wastewater treatment– $L_s2.L_n2$ are the most effective options: they can respectively reduce 42.9 percent, 41.3 percent and 46.8 percent of the COD load in the research site (table 13.9).

Key results: Effectiveness and feasibility

At the third stakeholder workshop, participants had group discussions on the effectiveness and feasibility of measures. The stakeholders mostly agreed on the following priorities for adaptation measures in Can Tho City: 1) upgrading reservoirs; 2) upgrading the drainage system (new water pipes); 3) increasing the permeable area; and 4) water saving and on-site wastewater treatment by septic tanks in households.

In addition, the key stakeholders provided combined solutions in order of priority according to temporal scales. The agreed *short-term combined measure* is "upgrading reservoir + water saving." This combined measure is currently feasible, easy to implement, and has a medium

Table 13.9. Effectiveness and investment for reducing flooding and improving water quality in future scenarios ($X_e10.X_n1$)

Scenarios	Whole study area			At representative point: 30/4 – Hoa Binh Street		Whole study area
Predicted population, rainfall and tide in 2030 & socioeconomic development as 2015 ($X_e10.X_n1$)	Flooding		Water quality	Flooding		
	Point	Volume (m^3)	COD concentration (mg/l)	Time (hour)	Level (m)	Investment cost level
No action – L_s0	326	1,270,603	148	8.71	0.47	-
Increasing permeable area (~1% of the total study area) – L_s1	0.6%	0.6%	1.4%	1.3%	2.1%	Very low
Upgrading reservoir – L_s2	3.4%	9.1%	0%	11.5%	2.1%	Medium
Upgrading drainage system (a new water drainage pipeline) – L_s3				97%	89.4%	Very high
Water saving – L_n1	0.3%	25.5%	-18.2%	55.3%	4.3%	Very low
On-site wastewater (WW) treatment (septic tank in households) – L_n2	0%	0%	39.9%	0%	0%	Very low
Increasing permeable area + water saving – $L_s1.L_n1$	0.3%	26.1%	-17.6%	55.5%	6.4%	Very low
Upgrading reservoir + water saving – $L_s2.L_n1$	4.3%	30.9%	-18.2%	58.7%	4.3%	Medium
Upgrading drainage system (a new water drainage pipeline) + water saving – $L_s3.L_n1$				97.1%	89.4%	Very high
Increasing permeable area+ on-site WW treatment (septic tank) – $L_s1.L_n2$	0.6%	0.6%	40.5%	1.3%	2.1%	Very low
Upgrading reservoir + on-site WW treatment (septic tank) – $L_s2.L_n2$	3.4%	9.1%	41.2%	11.5%	2.1%	Medium
Upgrading drainage system (a new water drainage pipeline) + on-site WW treatment (septic tank) – $L_s3.L_n2$				97.2%	89.4%	Very high

Robust	0%		100%
Not robust	0%		-100%

Table 13.10. Effectiveness of measures and investment for reducing flooding and improving water quality in future scenarios ($X_e 12.X_n 1$)

Scenarios	Whole study area			At representative point: 30/4 – Hoa Binh Street		Whole study area
Predicted population, rainfall and tide in 2030 and socioeconomic development 10% faster than the city's planning ($X_e 12.X_n 1$)	Flooding		Water quality	Flooding		
	Point	Volume (m^3)	COD concentration (mg/l)	Time (hour)	Level (m)	Investment cost level
No action – $L_s 0$	337	1,986,618	126	8.90	0.51	-
Increasing permeable area (~1% of the total study area) – $L_s 1$	0%	0.4%	1.1%	1.1%	3.9%	Very low
Upgrading reservoir – $L_s 2$	3.9%	11.1%	10.3%	12.4%	3.9%	Medium
Upgrading drainage system (a new water drainage pipeline) – $L_s 3$				97.0%	88.2%	Very high
Water saving – $L_n 1$	3.3%	49.7%	-34.9%	27.4%	9.8%	Very low
On-site wastewater (WW) treatment (septic tank) – $L_n 2$	0%	0%	42.9%	0%	4%	Very low
Increasing permeable area + water saving – $L_s 1.L_n 1$	3.9%	50.1%	-34.9%	27.5%	9.8%	Very low
Upgrading reservoir + water saving – $L_s 2.L_n 1$	6.8%	53.5%	-34.1%	38.8%	9.8%	Medium
Upgrading drainage system (a new water drainage pipeline) + water saving – $L_s 3.L_n 1$				97.1%	88.2%	Very high
Increasing permeable area+ on-site WW treatment (septic tank) – $L_s 1.L_n 2$	0%	0.4%	41.3%	1.1%	3.9%	Very low
Upgrading reservoir + on-site WW treatment (septic tank) – $L_s 2.L_n 2$	3.9%	11.1%	46.8%	12.4%	3.9%	Medium
Upgrading drainage system (a new water drainage pipeline)+ on-site WW treatment (septic tank) – $L_s 3.L_n 2$				97.0%	88.2%	Very high

Robust	0%		100%
Not robust	0%		-100%

investment cost. The *long-term combined measure* is "upgrading reservoir + upgrading drainage system (a new water drainage pipeline) + on-site WW treatment by septic tanks in households." This combined measure is a more time-consuming solution with significant investment costs and is dependent on city residents' perceptions.

In general, from the study team's research findings and key stakeholders' professional experience, the majority of the stakeholders agreed that the upgrading of reservoirs and the drainage system are the most appropriate solutions to reduce flooding problems and improve water quality in Can Tho City. Stakeholders indicated that upgrading the drainage system would be highly efficient but not feasible in the current context due to its high investment cost. There was a need for a planning blueprint for the city that contains detailed maps and technical information about the city's sewage system and water levels at present and as projected. In contrast, reservoir improvement was feasible because it is easier to implement and less time-consuming. The only concern about this intervention was that flood prevention would be confined to areas/points/routes around the reservoir. However, Can Tho City has been implementing and upgrading Bun Xang Lake and excavating two further potential reservoirs within the city of 15 ha and 4.8 ha respectively. Combined with improved planning, this study's findings will support the city in selecting measures to reduce flooding and improve its current water quality.

With respect to increasing the permeable area in the city, the majority of stakeholders indicated that this approach was sound because of the low investment cost, relative ease of implementation and environmentally friendly aspects. However, the feasibility of implementing such an approach was relatively low due to difficulties in finding suitable areas/spaces in the city to implement this approach. Similarly, the two options of water saving and on-site wastewater treatment by installing septic tanks in households were also seen as effective in reducing flooding and improving water quality if they are implemented across the city. However, as these are mainly non-structural solutions, there is a need to increase community awareness in water use and management, especially for women in households. In addition, many Can Tho residents who were interviewed through the household survey thought that the risk of dealing with water scarcity in Can Tho City is very low due to the belief that both the underground and surface water resources of the city are abundant all year round. Therefore, there is a need for a long-term strategy to increase public awareness, develop a legal framework to support and encourage the adoption of these measures along with the implementation and enforcement of water management policies.

In the case of water saving and on-site wastewater treatment by household septic tanks, there is a need to pilot these approaches in certain areas to further assess the effectiveness of these measures and associated benefits before implementing them across the entire city.

Stakeholder engagement and policy feasibility

At the first national workshop the Stakeholder Analysis Network was used as an alternative approach for stakeholder mapping, which supports participants to identify the level of each stakeholder's influence/power and interest on issues relating to potable water scarcity in the city. After being identified, the stakeholders were divided into groups that included government, NGOs, associations, the private sector, individuals, etc. (table 13.11). The reasons for mapping the key stakeholders in terms of power and influence were also discussed (see table 13.12).

The five stakeholders that are in a position of power and have an interest in improving Can Tho City's water management are DOC, CCCO, DONRE, PC and the People's Committee Office (PCO) (see tables 13.11, 13.12). Among these, PC was considered to have the highest authority, influence and interest. Other stakeholders have lower interest in overall water management and influence because they play a role as consulting departments, and are themselves directly administered by the PC and PCO. Stakeholders that have significant interest but low influence are mostly private firms. They are interested in using water sources for supplying drinking water or the industrial processing of food. Some government departments, such as DOT, DOIC, and DOM, benefit from the water sources, but are not directly responsible for urban water management. A few stakeholders including DOF, DOCST, DOST, DOET, and DOLISA have very little interest in this issue or authority. These departments are in charge of providing finance, education, technology and to the urban water field. However, they are not involved in policymaking as well as urban water management, and are also directly administrated by Can Tho City's PC.

Table 13.11 Key stakeholders involved in water management in Can Tho City

- People's Committee (PC);
- Department of Natural Resources and Environment (DONRE);
- Department of Agricultural and Rural Development (DARD);
- Department of Planning and Investment (DPI);
- Department of Construction (DOC);
- Department of Transportation (DOT);
- Department of Medicine (DOM);
- Department of Culture, Sport and Tourism (DOCST);
- Department of Information and Communications (DOIC);
- Department of Finance (DOF);
- Department of Science and Technology (DOST);
- Department of Education and Training (DOET);
- Department of Labor, Invalids and Social Affairs (DOLISA);
- Institute of Economy and Society (IOES);
- Climate Change Coordination Office (CCCO);
- Water Supply and Sewerage Company (WSSC);
- Centre of Freshwater and Sanitization (CEFWS);
- Industrial Project Management Boards (IPMBs);
- ODA Project Management Boards (ODAPMBs);
- The Urban Project Companies (UPC);
- Woman Association;
- Youth Association;
- Universities;
- Research institutions;
- Non-governmental organizations (NGOs);
- Urban residents, companies, factories and enterprises.

Stakeholder engagement is a key process in urban water management. A participatory approach was used to engage and share the ownership of the study's process and outcomes with local research partners at Can Tho University and other key organizations. The participatory nature of the social and political acceptance of its findings. The ownership of the findings was shared between research partners or transferred to the in-country partners. The stakeholder engagement process was coordinated through the three national workshops in which local stakeholders played a central role. The process design, materials and facilitation of the workshops were provided collaboratively by Can Tho University, the Climate Change Coordination Office of Can Tho City and Stockholm Environmental Institute to ensure they would be appropriate for the local context.

13.12 Key stakeholders and their positions in Can Tho City's water management

Key stakeholder	Quadrant	Reasons provided
People's Committees (PC), People's Committee Office (PCO), DONRE, DOC, and CCCO	Engage closely and high influence	These stakeholders directly manage issues relating to urban water scarcity in the city
DPI, DARD, WSSC, CEFWS and IPMBs	Engage closely and medium influence	They are the main water supply companies or the governmental departments for planning and investment projects relating to urban water issues in the city
DOT, DOIC, DOM, IOES, urban project companies, Universities/Research Institutes and army	Medium engagement and medium influence	They benefit from water sources, but they are not very relevant to urban water scarcity management and decision-making
Urban residents, companies, factories, enterprises	Engage closely and low influence	These stakeholders use water daily but have low influence in deciding issues relating to the scarcity of clean water in the city
DOF, DOCST, ODAPMBs, DOST, DOET, DOLISA, Women's Association, Youth Association	Keep informed	These stakeholders are only the governmental departments in providing finance, education, technology; and clean water scarcity is only one of their areas of interest

Conclusion and recommendations

Floods and water pollution are factors leading to further challenges in Can Tho City's water management, especially in conditions of potable water scarcity. With the cooperation of the project's key stakeholders, this research has produced a number of usable results that can deal with these problems. Key measures used to deal with these challenges include (in order of priority) building or upgrading the city's reservoirs, upgrading the drainage system, increasing the permeable area, saving water and installing on-site household wastewater treatment (septic tanks). In terms of flood prevention, single or combined measures including building or upgrading the reservoir/s and the city's drainage system are the most effective solutions with a medium or higher level of investment needed, while water saving (with the important role of women) or wastewater treatment in households are projected to be highly cost-effective ways of improving water quality.

From the research findings, there are a number of issues as well as recommendations relating to policies, strategies and planning that need to be considered:

- Water regulation reservoirs and the water drainage network should be upgraded or constructed to improve flood water drainage capacity and rain water harvesting during the wet season and high tides, and used in place of groundwater pumping during the increasingly longer dry seasons;
- Investments in decentralized domestic wastewater treatment systems (septic tanks) and drainage networks are needed to meet rapid urbanization and industrialization to reduce damage to human health, economic losses and environmental degradation;
- Household water use can be reduced through education campaigns that target women in particular as they are the main decision-makers for issues related to water saving and management;
- Stakeholder engagement is one of the most important factors leading to the effectiveness of the urban water management in general, and in potable water management in the city.

The economic aspects including monetary benefits such as reduced material and labor costs, and non-monetary benefits of each measure or combination of measures such as impacts and improvements on health, transport and livelihood activities should be further analyzed, assessed and compared so that decision-makers can make informed choices about optimal solutions for effective urban water management in Can Tho City.

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14

Synthesis: Robust strategies for uncertain climate futures

Louis Lebel, Rajesh Daniel and Chayanis Krittasudthacheewa

The impacts of current development on resources and human well-being are not always easy to predict; the challenge of assessing impacts in the future—with its barely imagined technologies, unforeseen crises, and changed environments—is inordinately more difficult. Decisions made now, for example, with respect to the design of large-scale and long-lived water infrastructure, or to the conversion of wetlands for human settlements, can have major implications for risks and opportunities in the coming decades. In these situations, it often makes sense to pursue robust decisions and supporting strategies, that is, those which are likely to work out satisfactorily under a wide range of plausible conditions, as opposed to the conventional logic of optimizing to some hoped for or average future.

In this final chapter we synthesize what the preceding chapters have to say about the search for robust development strategies in the Mekong Region. We were especially interested in insights about impacts to be addressed, enabling conditions, the methods used to identify strategies, and the implications for policy and practice. The rest of the chapter is organized around four propositions.

Base rural development on improving ecosystem services

The opening proposition is that rural development strategies based on improving ecosystem services provision must be more robust. The main argument is that agricultural activities depend strongly on water and soil related services provided by surrounding natural ecosystems and some types of agricultural land-use systems. These services, like wetland storage of surplus wet season flows, are important for dealing with extreme climate events.

The Central Indochina Dry Forest Ecosystem contains perhaps 20,000 small wetlands. Many of these wetlands are already disturbed, while others are at risk of being converted to intensive agriculture (chap. 3, this volume). The importance of smaller wetland landscapes for biodiversity conservation and as a source of ecosystem services needs to be more widely recognized, and prioritized, in policy development.

The analysis of water balances in the Prek Thnot River Basin (chap. 10) identified upstream water infrastructure as an important influence on environmental flows and availability of water for irrigation further downstream during the dry season. Another study in Thailand (chap. 12), concluded that dredging a swamp would increase water storage useful to alleviate drought in one of the sub-basins. This can be considered as taking into account (modified) wetland ecosystem services—storing wet season surplus water for dry season use.

Modeling of deforestation scenarios in the Chindwin basin suggests the loss of forest cover would substantially increase river flows and thus the risk of severe floods (chap. 11), underlining the importance of flood regulating services for development. The carbon sequestration services provided by forests is the core of the internationally negotiated REDD+ programmes. In chapter 5, the authors show that developing a national REDD+ strategy is a complex process because understanding of the drivers of deforestation and forest degradation varies among stakeholders whose interests in forest use and conservation also diverge. While national forest monitoring systems are important to policy justification and evaluation, proponents of REDD+ strategy also need to show that pursuing such a strategy makes economic sense.

The welfare of forest-dependent households is by definition tightly coupled to the ecosystem services provided by forest landscapes. As for ecosystem-based development strategies, one limitation faced by forest-dependent households is that a lack of capital restricts their livelihood options, in particular, for non-farm and non-forest-based activities (chap. 4).

Pursue economic integration that is inclusive

The second proposition is that economic integration strategies that create opportunities for all to make links across borders should be more robust.

The key argument here is that flow-on effects from integration such as enhanced trade, investment or labor mobility, help to deal with differences among places. These flow-on effects could help to address varying socioeconomic conditions with time, *provided* they do not exclude the social groups most in need of access to land, water and other resources. That is the inclusive catch.

The East-West Economic Corridor transport infrastructure projects help drive forest land conversion to agriculture. Social impacts have been varied thus far, with improvements in access to finance, education and health services traded-off against losses in social capital (chap. 4). The study notes with concern increases in social violence as a consequence of the corridor. Studies of adaptation to climate change in chapter 6 also raised concerns with the "individualistic nature of adaptation" which erodes social capital that community-based responses driven by their inclusive-orientation would maintain.

Support climate-compatible practices

Climate-compatible practices are concerned with adaptation or mitigation. This third proposition is explicitly concerned with the severity and uncertainties of future climate change and their implications for adaptation. Climate-compatible, or more explictly, climate change-compatible, development argues that to be robust you need to take uncertainties into account now, especially for decisions with long-term consequences, low reversibility, and long investment horizons.

Most adaptation measures taken by rural households have been reactive, short-term, and protection-based (chap. 6). Likewise, local authorities have not adopted anticipatory strategies despite knowledge of increased intensity and frequency of extreme events. Clearly, more proactive and collaborative approaches are needed to generate successful adaptations. In the case study of Cambodia, the authors of chapter 10 see the strengthening of extension support as a critical source for both trusted information and new technologies.

The authors of chapter 9 document changes in Lao PDR's climate and claim that "communities have responded accordingly through adaptive measures." They also recommend additional measures such as improving water storage and irrigation systems. One study in Thailand suggests both the need for increasing water storage and reducing demand during critical periods by shifting the cropping calendar (chap. 12). The groundwater extraction option is constrained by risks of rising salinity. In the Chindwin case study, the use of groundwater appears to be a robust strategy for improving water coverage for domestic and industrial uses (chap. 11).

Comparative studies of how loss and damage systems come into play following disasters suggest that building resilience requires paying more attention to the "underlying drivers of vulnerability" so support and services reach all groups (chap. 8). The study also highlights the importance of addressing governance challenges such as fragmentation and poor coordination, a point also made for drought management in Myanmar (chap. 11).

In urban areas such as Can Tho City, Vietnam, managing inundation is primarily viewed through an infrastructure lens, although the importance of increasing permeable surfaces is recognized (chap. 13). Modeling analysis suggests that upgrading the drainage system would improve flood resilience in the city.

Mitigation is the other side of climate-compatible practices. The burning of post-harvest rice straw is a common practice in Thailand, Vietnam and Cambodia. One alternative that would help reduce air pollution and greenhouse gas emissions as well as help maintain soil quality would be to convert the straw into fuel. Chapter 7 shows that solid fuels derived from rice straw are a plausible substitute for fuelwood; however, where LPG is in use, adoption would depend on their comparative costs. One of the key challenges of pursuing more climate-compatible technologies is that information on non-open burning methods needs to be more widely shared. NGO partners may play an important role in such communication, given experience with improved cookstoves.

Coproduce knowledge for better strategies

The final proposition is cross-cutting. It aims to put research in its proper place. The idea is that if you combine, or confront, knowledge from different sources you end up with a better understanding of the problem and thus solutions tailored to particular places, needs and capacities. And you develop mutual respect, even trust.

Several chapters in this book cite the importance of combining scientific or expert knowledge with local knowledge for identifying workable solutions and strategies. Chapter 2 perhaps goes the furthest, treating research as facilitation in which local stakeholders contributed to the identification of challenges, questions and designs. This approach led to "concrete progress in addressing the real-world problem identified" and further collaboration. At the same time entrenched conflict over wetland zoning could not be overcome in one of the cases, pointing out that the approach is not a panacea. The knowledge partnership needs to be continued as a long-term engagement among all the parties concerned to implement solutions.

Knowledge coproduction creates trust, and vice versa, trust makes coproduction easier. Information that is reliable and trusted is important for dealing with the uncertain and "creeping risks" from a changing climate (chap. 10). The SUMERNET strategy of working with boundary partners often helped build trust and enable social learning (chap. 2), or at least made communication of important information about innovations easier (chap. 8). The robust decision support (RDS) framework helped structure conversations among key stakeholders around their perceptions of problems, needs, uncertainties and potential solutions important to water resources planning (chap. 13).

Robust strategies often need to be traded off among competing interests. Some strategies may help meet one need, but may make it more difficult for other needs to be fulfilled (chap. 12). This requires prioritization and negotiation among different parties in a process which considers the consequences as well as costs and benefits associated with the implementation of specific strategies (chap. 13).

Conclusion

The search for robust development strategies in the Mekong Region continues. Four ways which should help in moving forward are proposed, namely: base rural development on improving ecosystem services; pursue economic integration that is inclusive; support climate-change compatible development; and, coproduce knowledge for better strategies. The evidence in support of these propositions in this book is mixed, in part, because of limitations in coverage and data, but also some methodological challenges.

More research is needed, for instance, on the costs and feasibility of following robust or resilience-building strategies and how actors perceive these relative to risk reduction benefits and trade-offs between different sectors and interests. Nevertheless, enough is known to conclude that there is a need for more socially inclusive and gender-responsive, strategic, long-term, development policies which take climate uncertainty seriously.

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Appendix

Figure 10.5. The Failure Matrix for environment flows (L1 no strategy or "business as usual"; L2 hydropower development in the upstream portion of the basin; L3 agriculture expansion associated with irrigation development; and L4 combination of L2 and L3).

Environmental_flow

		Sub-Basin 3				Sub-Basin 5			
Land Use Change	Climate Change	L1	L2	L3	L4	L1	L2	L3	L4
1.High Rate of Deforestation	Average	22%	22%	22%	22%	21%	46%	21%	46%
	Dry Climate	25%	24%	24%	24%	24%	49%	24%	49%
	Wet Climate	20%	20%	20%	20%	19%	40%	19%	40%
2. Medium rate of Deforestation	Average	22%	22%	22%	22%	21%	46%	21%	48%
	Dry Climate	25%	24%	25%	24%	24%	49%	24%	49%
	Wet Climate	20%	20%	20%	20%	19%	40%	19%	40%
3. Low rate of Deforestation	Average	22%	22%	22%	22%	21%	46%	21%	46%
	Dry Climate	25%	24%	25%	24%	24%	49%	24%	49%
	Wet Climate	20%	20%	20%	20%	18%	40%	18%	40%

Measure V.. 19% – 40%

Figure 10.6. The Failure Matrix for water levels in the selected sub-basins 3 and 5

Water_level

		Strategy							
		Sub Basin 3				Sub Basin 5			
Land Use Change	Climate Change	L1	L2	L3	L4	L1	L2	L3	L4
1. High Rate of Deforestation	Avg Climate	38%	38%	38%	38%	30%	56%	30%	56%
	Dry Climate	39%	39%	39%	39%	34%	58%	33%	58%
	Wet Climate	34%	34%	34%	34%	28%	50%	28%	50%
2. Medium Rate of Deforestation	Avg Climate	38%	38%	38%	38%	30%	56%	30%	56%
	Dry Climate	39%	39%	39%	39%	34%	58%	34%	58%
	Wet Climate	34%	34%	34%	34%	28%	51%	28%	51%
3. Low Rate of Deforestation	Avg Climate	38%	38%	38%	38%	30%	56%	30%	56%
	Dry Climate	39%	39%	39%	39%	34%	58%	34%	58%
	Wet Climate	34%	34%	34%	34%	28%	51%	28%	51%

Measure V.. 20% – 56%

Figure 11.8. Comparison of percentage of failure of domestic water coverage between no strategy and using groundwater strategy in selected four sub-basins under climate change and population change scenarios

		Strategy / Subbasin							
		No Strategy				Sustainable ground water pumping			
Climate Change	Population	Myittha	Monywa	Yinmabin	Lower Monywa	Myittha	Monywa	Yinmabin	Lower Monywa
Dry	Decrease	40%	0%	0%	0%	2%	0%	0%	0%
	Medium increase	65%	27%	51%	67%	3%	0%	1%	0%
	Rapid increase	77%	49%	61%	70%	9%	0%	13%	6%
	Remain same	42%	0%	3%	0%	2%	0%	0%	0%
Normal	Decrease	34%	0%	0%	0%	2%	0%	0%	0%
	Medium increase	51%	23%	44%	61%	2%	0%	1%	0%
	Rapid increase	68%	40%	49%	66%	7%	0%	13%	6%
	Remain same	34%	0%	3%	0%	2%	0%	0%	0%
Wet	Decrease	34%	0%	0%	0%	2%	0%	0%	0%
	Medium increase	50%	23%	44%	61%	2%	0%	1%	0%
	Rapid increase	68%	40%	48%	66%	7%	0%	13%	6%
	Remain same	34%	0%	3%	0%	2%	0%	0%	0%

Figure 11.9. Comparison of percentage of failure of irrigation water coverage between no strategy and strategy in reducing loss in irrigation system in selected sub-basins under climate change and land-use change scenarios

		Strategy / Node			
		No Strategy		Reduce loss in irrigation system	
Climate Change	**Land use change**	Monywa	Lower Monywa	Monywa	Lower Monywa
Dry	Change crop type	26%	24%	22%	16%
	Increase deforestation	24%	21%	17%	9%
	No Change	24%	21%	17%	9%
Normal	Change crop type	18%	18%	13%	12%
	Increase deforestation	16%	15%	7%	6%
	No Change	16%	15%	7%	6%
Wet	Change crop type	18%	18%	14%	13%
	Increase deforestation	17%	16%	9%	7%
	No Change	17%	16%	9%	7%

Figure 11.10. Comparison of percentage of failure of environmental flows between no strategy and watershed conservation strategy at five selected locations in the Chindwin River Basin under climate change and land-use change scenarios

		Strategy									
		No Strategy in place					Watershed Consercation				
Climate Change	Land use change	Hkanti	Homalin	Kalaywa	Mawalaik	Monywa	Hkanti	Homalin	Kalaywa	Mawalaik	Monywa
Dry	1. No Change	26%	29%	24%	30%	25%	26%	29%	24%	30%	25%
	2. Increase Deforestation	27%	30%	25%	31%	25%	27%	30%	25%	31%	25%
	3. Change crop type	27%	30%	25%	31%	25%	27%	30%	25%	31%	25%
Normal	1. No Change	5%	13%	5%	15%	9%	5%	13%	5%	15%	8%
	2. Increase Deforestation	7%	15%	7%	16%	10%	7%	15%	7%	16%	10%
	3. Change crop type	7%	15%	7%	16%	10%	7%	15%	7%	16%	10%
Wet	1. No Change	5%	10%	5%	11%	9%	5%	10%	5%	11%	8%
	2. Increase Deforestation	6%	10%	6%	11%	9%	6%	10%	6%	11%	9%
	3. Change crop type	6%	11%	6%	11%	9%	6%	11%	6%	11%	9%

Figure 12.8. Performance matrix for domestic sector under a wide range of scenarios in major sub-districts in Huay Sai Bat River Basin

Dometic Use

		Strategy																													
		Dun Sat					Kham Yai					Nam om					Nong Ko					Phimun					Sai_Thong				
Climate Change	**Land use change**	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4
Avg Climate	1. Same land use	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%
	2. Sugar to Rubber + Rice to Sugar	2%	0%	2%	2%	1%	1%	0%	1%	2%	1%	1%	0%	1%	2%	1%	1%	0%	1%	2%	1%	1%	0%	1%	2%	1%	1%	0%	1%	2%	1%
	3. Increase irrigation	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%	2%	1%	2%	3%	2%
	4. Combination 2+3	1%	0%	1%	2%	1%	1%	0%	1%	2%	1%	1%	0%	1%	2%	1%	1%	0%	1%	2%	1%	1%	0%	1%	2%	1%	1%	0%	1%	2%	1%
Dry Climate	1. Same land use	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%
	2. Sugar to Rubber + Rice to Sugar	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%
	3. Increase irrigation	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%
	4. Combination 2+3	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%	2%	1%	2%	4%	2%
Wet Climate	1. Same land use	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%
	2. Sugar to Rubber + Rice to Sugar	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%
	3. Increase irrigation	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%	2%	0%	2%	3%	2%
	4. Combination 2+3	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%	1%	0%	1%	1%	1%

%Failure (AL = 3%)
0% 100%

Figure 12.9. Performance matrix for industrial sector under wide range of scenarios for C00, C06 and C07 sub-basins

Industrial Use

		Subbasins / Strategy														
		C00					C06					C07				
Climate Change	**Land use change**	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4
Avg Climate	1. Same land use	2%	2%	2%	3%	2%	2%	2%	2%	3%	2%	2%	2%	2%	3%	2%
	2. Sugar to Rubber + Rice to Rubber	2%	2%	2%	4%	2%	2%	2%	2%	4%	2%	2%	2%	2%	4%	2%
	3. Increase Irrigation	2%	2%	2%	3%	2%	2%	2%	2%	3%	2%	2%	2%	2%	3%	2%
	4. Combination 2+3	2%	2%	2%	4%	2%	2%	2%	2%	4%	2%	2%	2%	2%	4%	2%
Dry Climate	1. Same land use	3%	2%	2%	5%	3%	3%	2%	2%	5%	3%	3%	2%	2%	5%	3%
	2. Sugar to Rubber + Rice to Rubber	3%	2%	2%	5%	3%	3%	2%	2%	5%	3%	3%	2%	2%	5%	3%
	3. Increase Irrigation	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%	3%	2%	3%	5%	3%
	4. Combination 2+3	3%	2%	2%	5%	3%	3%	2%	2%	5%	3%	3%	2%	2%	5%	3%
Wet Climate	1. Same land use	1%	1%	1%	3%	1%	1%	1%	1%	3%	1%	1%	1%	1%	3%	1%
	2. Sugar to Rubber + Rice to Rubber	1%	1%	1%	2%	1%	1%	1%	1%	2%	1%	1%	1%	1%	2%	1%
	3. Increase Irrigation	1%	1%	1%	3%	1%	1%	1%	1%	3%	1%	1%	1%	1%	3%	1%
	4. Combination 2+3	1%	1%	1%	2%	1%	1%	1%	1%	2%	1%	1%	1%	1%	2%	1%

%Failure (AL =5%)
0% 100%

Figure 12.10. Performance matrix for irrigation sector under wide range of scenarios for C04, C06 and C07 sub-basins

Crop water needs

		Subbasins / Strategy														
		C04					C06					C07				
Climate Change	**Landuse Change**	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4
Avg Climate	1. Same Land Use	4%	1%	0%	5%	4%	9%	9%	1%	13%	9%	45%	45%	45%	49%	45%
	2. Change Sugar to Rubber +Rice to Sugar in upstream	3%	1%	0%	4%	3%	9%	9%	1%	13%	9%	45%	45%	45%	49%	45%
	3.Expand rice irrigation in downstream	4%	2%	0%	6%	4%	9%	9%	1%	13%	9%	48%	48%	48%	50%	48%
	4.Combination 2+3	3%	1%	0%	4%	3%	9%	9%	1%	13%	9%	48%	48%	48%	50%	48%
Dry Climate	1. Same Land Use	7%	3%	0%	9%	6%	13%	13%	1%	18%	13%	47%	47%	47%	49%	47%
	2. Change Sugar to Rubber +Rice to Sugar in upstream	4%	2%	0%	6%	4%	13%	13%	1%	18%	13%	47%	47%	47%	49%	47%
	3.Expand rice irrigation in downstream	7%	3%	0%	10%	7%	13%	13%	1%	18%	13%	49%	49%	49%	51%	49%
	4.Combination 2+3	4%	2%	0%	6%	4%	13%	13%	1%	18%	13%	49%	49%	49%	51%	49%
Wet Climate	1. Same Land Use	4%	1%	0%	6%	3%	8%	7%	0%	11%	8%	42%	42%	42%	46%	42%
	2. Change Sugar to Rubber +Rice to Sugar in upstream	2%	1%	0%	3%	2%	7%	7%	0%	11%	7%	42%	42%	42%	46%	42%
	3.Expand rice irrigation in downstream	4%	1%	0%	6%	4%	8%	7%	0%	11%	8%	45%	45%	45%	48%	45%
	4.Combination 2+3	2%	1%	0%	3%	2%	7%	7%	0%	11%	7%	45%	45%	45%	48%	45%

%Failure (AL= 20%)
0% 100%

Figure 12.11. Performance matrix for environmental sector under wide range of scenarios for basin outlets in C00 (location 1), C04 (location 2) and C07 (location 3)

Environmental Flow

		Strategy														
		Location1					Location 2					Location 3				
Climate Change	Land use change	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4	S0	S1	S2	S3	S4
Avg Climate	1. Same land use	25%	23%	25%	32%	25%	21%	20%	21%	27%	22%	28%	28%	28%	33%	28%
	2. Change Sugar to Rubber + Rice to Sugar in upstream	24%	23%	24%	33%	24%	18%	17%	18%	22%	18%	26%	26%	26%	31%	26%
	3. Expand Rice Irrigation in downstream	24%	22%	24%	31%	24%	22%	21%	21%	27%	22%	28%	28%	28%	33%	28%
	4. Combination 2 +3	24%	23%	24%	33%	24%	18%	17%	18%	22%	18%	26%	26%	26%	31%	26%
Dry Climate	1. Same land use	31%	29%	31%	36%	31%	26%	25%	26%	32%	26%	32%	32%	32%	39%	32%
	2. Change Sugar to Rubber + Rice to Sugar in upstream	29%	28%	29%	36%	30%	23%	23%	24%	27%	24%	30%	30%	30%	36%	30%
	3. Expand Rice Irrigation in downstream	30%	28%	30%	34%	31%	26%	26%	26%	32%	26%	32%	32%	32%	39%	32%
	4. Combination 2 +3	29%	28%	29%	36%	30%	23%	23%	24%	27%	24%	30%	30%	30%	36%	30%
Wet Climate	1. Same land use	22%	21%	21%	28%	22%	17%	17%	17%	24%	17%	25%	25%	24%	30%	25%
	2. Change Sugar to Rubber + Rice to Sugar in upstream	21%	20%	21%	29%	21%	16%	16%	16%	18%	16%	22%	23%	22%	28%	22%
	3. Expand Rice Irrigation in downstream	21%	20%	21%	28%	21%	17%	17%	17%	24%	17%	25%	25%	25%	30%	25%
	4. Combination 2 +3	21%	20%	21%	29%	21%	16%	16%	16%	18%	16%	22%	23%	22%	28%	22%

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In the countries of the Mekong Region: Cambodia, Lao PDR, Myanmar, Thailand and Vietnam, environmental sustainability continues to be a major concern. As rapid economic growth continues, environmental degradation is taking a huge toll on ecosystems and livelihoods. Poverty and social inequality—including gender inequality—remain significant challenges.

In addition, climate change is already causing severe negative impacts in many food-producing areas, increasing the risks of food and water insecurity. Droughts and floods occur with more frequency and intensity, with the most marginalized communities often the worst affected.

Our partners in the Sustainable Mekong Research Network (SUMERNET) have led interdisciplinary, cross-national studies on major policy issues; engaged with policymakers, planners and stakeholders; and built capacity among both researchers and policymakers. SUMERNET has attempted to better understand environmental challenges in the Mekong Region and provide policy solutions based on the close engagement of the project teams with local and national policymakers and other partners.

Each study sought the input and involvement of actors at all levels, from farmers, fishers and rural households to policymakers and administrators, the private sector, nongovernmental organizations and local academic experts.

It is our hope that this volume will help readers better understand the range and intensity of these environmental issues, including the impacts of climate change, and help support solutions at local, national and transboundary levels towards addressing these critical environmental and development challenges in the Mekong Region.

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