Mekong River Commission

Crop production for food security and rural poverty

Baseline and pilot modelling

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Abbreviations & Acronyms

ACO	Agricultural Census Office
ADB	Asian Development Bank
ADC	Agriculture Development Community
ADER	Average Dietary Energy Requirement
AEC	ASEAN Economic Community
AEZ	Agro Ecological Zone
ARCC	Mekong Adaptation and Resilience to Climate Chang
ASEAN	Association of Southeast Asian Nations
BDP	Basin Development Plan
CADI	Cambodian Agriculture Development Institute
CALA	Climate Change and Adaptive Livelihood Agriculture Community
CCAI	Climate Change and Adaptation Initiative
DARD	Department of Agriculture and Rural Development
DEC	Dietary Energy Consumption
DEM	Digital Elevation Model
DOAE	Department of Agricultural Extension
DOS	Department of Statistics
DSSAT	Decision Support System for Agro technology Transfer
ESCAP	Economic and Social Commission for Asia and the Pacific
FAO	Food and Agricultural Organization
FDI	Foreign Direct Investment
GAP	Good Agriculture Practice
GCM	Global Circulation Model
GDP	Gross Domestic Product
GHI	Global Hunger Index
GIEWS	Global Information and Early warning System
GIS	Geographical Information System
GMS	Greater Mekong Sub-region
GOL	Government of Lao

HLTF	High Level Task Force
HRU	Hydrological Unit Analysis
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
LDD	Land Development Department
LMB	Lower Mekong Basin
MDER	Minimum Dietary Energy Requirement
MDGs	Millennium Development Goals
MRC	Mekong River Commission
MTs	Million Tonnes
NMC	National Mekong Committee
NTFPs	Non-Timber Forest Products
OARD	Offices of Agricultural Research and Development
PAFO	Provincial Agriculture and Forestry Office
PRECIS	Providing Regional Climates for Impact Studies
PREMSU	Poverty Reduction and Economic Management Sector Unit
PRC	People Republic of China
RAPA	Regional Office for Asia and Pacific
RCM	Regional Climate Model
RUA	Royal Agriculture University
SE Asia	South East Asia
SEDS	Socio-Economic Development Strategy
SNV	Netherlands Development Organization
SHDP	Smallholder Development Program
SWAT	Soil and Water Assessment Tool
UN	United Nations
UNDP	United Nations Development Programme
USD	United States Dollar
USDA	United States Department of Agriculture

USAID	United States Agency for International Development
WFP	World Food Programme

Executive summary

The Lower Mekong Basin (LMB) covers an area of approximately 606,000 km^2 within the countries of Cambodia, Lao PDR, Thailand, and Viet Nam. This densely populated region, which is home to more than 60 million people, is heavily reliant on natural resources and ecosystems for its social, economic and biophysical well-being. Agriculture is the single most important economic activity for around 65 million people in the LMB. More than 10 million hectares of the LMB's total cultivated land is used to produce rice. Upland areas where the slopes can be steep have often been cleared for shifting agriculture growing hill rice, maize and other subsistence crops. Commercial crops include coffee, cassava, soybean and sugarcane.

While continued economic growth has led to a significant improvement in living standards in recent years, many of the basin's population still live in poverty. The livelihoods and food security of most of the basin's rural inhabitants are closely linked to the Mekong and its waterways. The river is a source of fish and other aquatic products for food and income, water to grow crops, and a transport route which provides access to markets. This close relationship also means that people are particularly vulnerable if the river and its wetland ecosystems become degraded. Distribution of rainfall is highly variable throughout the basin along an increasing west-east gradient. Highest rainfall occurs on the western slopes of the Annamites of Lao PDR and Viet Nam, where mean annual rainfall can exceed 2,500mm/year, while the majority of Northeast Thailand and the North-eastern coastal region of the Delta experiences less than 1,200mm/yr. The combined effects of temperature and rainfall lead to strong seasonal reversal in the Mekong moisture budget which has shaped terrestrial vegetation characteristics.

The level of knowledge on water resources, land use and livelihoods in the Mekong Basin has been improving rapidly over the past decade. However, knowledge about the linkages between the current crop sector and food security and rural poverty is still insufficient. Knowledge on implications of the expansion of cropping on food security and poverty under natural resources constraints and their predicted changes occurring in the basin is also missing. The MRC Agriculture and Irrigation Programme (AIP) plans to implement a set of activities to monitor the trend of the

agriculture sector and to project the future and estimate its implications on food and poverty in the long run. In line with the programme of AIP, GIZ has offered financial contribution for an assessment of the conditions necessary to achieve the long-term food security and poverty reduction in the LMB under climate change conditions. Given this offer, the AIP team decided to draw a concrete road map towards such an assessment.

The overall objective of the study is to facilitate the long-term planning and policy-making in the crop production sector towards a food secured and poverty-alleviated future for the LMB under climate change. The following methods were used to accomplish the overall objective of the study.

Firstly, an overall review of the LMB in relation to hydro climate, biodiversity, socio-economic assessment including gender issues is made. This is followed by a review of the food security and poverty alleviation situation in each of the LMB countries together with expected impacts of climate change in agriculture, fisheries, livestock and ecosystem in the region. This was followed by country visits and consultations with national experts. These meetings were followed by visits to the Provincial and District agricultural development related government offices and selected farmers' fields (both upland dry area and low land wet area). The field visit team comprised a consultant, an AIP Programme Specialist, an NMC representative and an Agronomist/Production specialist from the line agency in addition to district agricultural extension specialists and area subject matter specialist.

For the pilot crop modelling, crop yield projections for rice, maize, cassava and soybean, which are the prime crops covering nearly most of the productive area in the region, were calculated based on the current trends of the yield using national level data for each country obtained from FAOSTAT for the period of 1990 to 2012. The data were later extrapolated using econometric modelling for the 2014-2050 period. Rice yield was forecasted using two models namely SWAT and DSSAT. The future climate and agronomic related data used to calibrate the model were collected from the previous research. Agronomic and crop characteristics related data for crop modelling was retrieved from the experiment which was conducted by the Rice Research Center in Khon Kaen, Roi Et and Ubon Ratchathani.

Production trends show an increase in the yield of the four crops in the LMB countries except for soybean in Cambodia which is showing a decrease in yield over time. The increase in the yields of the four major crops is attributed to change in varieties, chemical application, mechanisation, crop diversification and irrigation development.

Field visits provided glimpses of the current crop productivities, progress of agricultural intensification and commercialisation, and changes of rural societies. Significantly higher net income values than those reported in literatures were found in both rice and maize production. Though irrigated rice was found most profitable in average among the studied crops, there was significant variance. Some groups make fewer profits than rain-fed rice. Upland crop systems may be making comparable or higher profits with irrigated rice, too. Regular chemical and fertiliser use was common and direct seeding has become dominant for rice production in both rain-fed and irrigated fields in all seasons. Agricultural mechanisation is spreading in a form of outsourcing work while young family members move out to urban areas. Interviewed farmers all admitted expanding the gap between rich and poor, and received significant remittances from sons and daughters who work in major cities.

The available literatures pointed out that a significant proportion of the people living in the LMB parts of the four countries are poor. Despite the robust economic growth, Cambodia remains a poor country with more than 25 per cent of the population living on less than US$1.25 per day as of 2007. Although Lao PDR has experienced strong economic growth since 1990, approximately one-third of the population remains below the national poverty line and as of 2002, 44 per cent of the population was living on less than US$1.25 per day.

Food security also remains an issue in the LMB often in local scale and timing. The lack of storage capacity, inadequate transportation linkages and poor access to market information are major barriers to the improvement of agricultural yields and food security in Cambodia. Food security is also a major concern in Lao PDR where the FAO estimates that approximately 19 per cent of the population is undernourished. Impressive growth in Thailand has contributed to decreases in the number of undernourished people, falling from 30 per cent in 1990-1992 to 17 per cent in 2003-2005. However, the Northeast, which falls under the LMB region, had a lower Minimum Dietary Energy Requirement (MDER) and Average Dietary Energy Requirement (ADER) than the rest of the regions. The food security situation in Viet Nam has improved dramatically over the past two decades. In 1990-1992 approximately 31 per cent of the population was undernourished. The figure fell to 14 per cent by 2005.

Office visits provided information on relevant regional initiatives such as Agro-Ecological Zoning and drought monitoring, as well as national and provincial policies and programmes such as the agricultural census in Cambodia and development policy based on groundwater in Lao PDR.

Taking into account climate change scenarios, the future yields of rice, maize, cassava and soybean in Thailand are projected as a sample study using an econometric model. The results indicate that yields of rice, maize and cassava in Thailand will decrease by 2025 and 2050 under climate change scenarios while yield of soybean will slightly increase by 2025 and 2050.

The impact of climate change on rice yield in Northeast Thailand was also assessed via SWAT model and PRECIS dynamic downscaling. The SWAT model simulates the water availability in the study area and the crop production using the Erosion-Productivity Impact Calculator (EPIC) plant growth model. The results of the SWAT model showed the increasing temperature and decreasing precipitation in future periods. It predicted that rice yield would decrease up to 30 per cent in the future.

The CERES-Rice model available with the DSSAT Version 4.5 was also used in this study to assess the future rice yield in three provinces of NE Thailand. The model was calibrated and validated using details of some of the field experiments conducted by the Rice Research Centers in NE Thailand. To incorporate changes in climate variability and generate scenarios, the relative change between the GCM baseline period and the GCM future scenario were calculated. The predicted future climate scenario was applied to the calibrated CERES-Rice model for the study sites to determine the impacts on rice yield during the three future periods. The impacts were then assessed by computing the changes in the average yield of the future periods with respect to the yield obtained for the simulated daily weather data for the baseline period. Rice yield is projected to decrease during all three periods under A2 scenario, although the percentage decrease is very small during early and mid-century periods. Projections under B1 scenario do not show any clear pattern of increase or decrease in rice yields in any of the Provinces.

1. Introduction

1.1 Mekong River Basin

The Mekong River in Southeast Asia is among the greatest rivers in the world. Its estimated length (4,909 km) and its mean annual volume (475 km3) make it the tenth largest in the world (MRC 2005; Shaochuang et al. 2007). The Mekong has always been the integral element in the lives of the people who live within its 810,000 square kilometre drainage. It rises in Tibet, flows down through China for about 2,500 km, and then for another 2,400 km between Laos and Myanmar, Laos and Thailand, into Cambodia and down to the Delta in Viet Nam before it empties into the South China Sea. The six countries that share the river (Cambodia, People's Republic of China, the Lao People's Democratic Republic, Myanmar, Thailand, and Viet Nam) have rather different relationships with the river, depending largely on where the river affects them. In the PRC (where it is called the Lancang) the Mekong cuts through deep mountain gorges in Yunnan Province before beginning to flatten out as it enters Lao PDR and Myanmar. For mountainous Lao PDR, the river is a dominant source of fish, transport, irrigation water, and hydropower on its tributaries. For Thailand, it provides similar uses, but is not as dominant because the Chao Phraya River services the most productive part of the country, just as the Irrawaddy and Salween do in Myanmar.

The river and its floodplains are particularly important for the Lower Mekong floodplains downstream from the Cambodian provincial town of Kratie. In this area the annual rhythm of the river is most visible as the flood waters extend the river to vast floodplains, supporting highly productive fisheries and rice cultivation. For Cambodia, the Mekong was the essential source of its spectacular civilization (with the temples of Angkor Wat and its predecessors), based on the Tonle Sap (Great Lake), which is seasonally fed by the river. And for Viet Nam, the delta of the river provides some of the country's most important rice-growing lands, along with a rich fishery.

The Mekong is also among the world's most pristine large rivers, supporting an exceptionally diverse and productive freshwater ecosystem that provides livelihood and food for millions of people. The most important water-related resources in the basin are rice and fish as well as other aquatic animals and plants (MRC 2003). The river and its numerous tributaries, backwaters, lakes, and swamps support many unique ecosystems and a wide range of globally-threatened species.

Figure 1.1: The Mekong River Basin

1.2 Lower Mekong Basin (LMB)

The Lower Mekong Basin (LMB) covers an area of approximately 606,000 km^2 within the countries of Cambodia, Lao PDR, Thailand, and Viet Nam. This densely populated region, which is home to more than 60 million people, is heavily reliant on natural resources and ecosystems for its social, economic and biophysical well-being. For the primarily rural economies of Cambodia, Lao PDR and the Mekong Delta of Viet Nam, the river is the lifeline of the local people as it supports directly the livelihoods of millions of fishers and farmers. Agriculture is the single most important economic activity in the LMB. More than 10 million hectares of the LMB's total cultivated land is used to produce rice. Upland areas where the slopes can be steep have often been cleared for shifting agriculture, growing hill rice, maize and other subsistence crops. Commercial crops include coffee, cassava, soybean and sugarcane. Rapidly increasing plantations of rubber are changing the landscape throughout the region. During the past two decades ecological transformation of the basin has accelerated due to large scale infrastructure development such as hydropower and road networks which provide access to other resource uses.

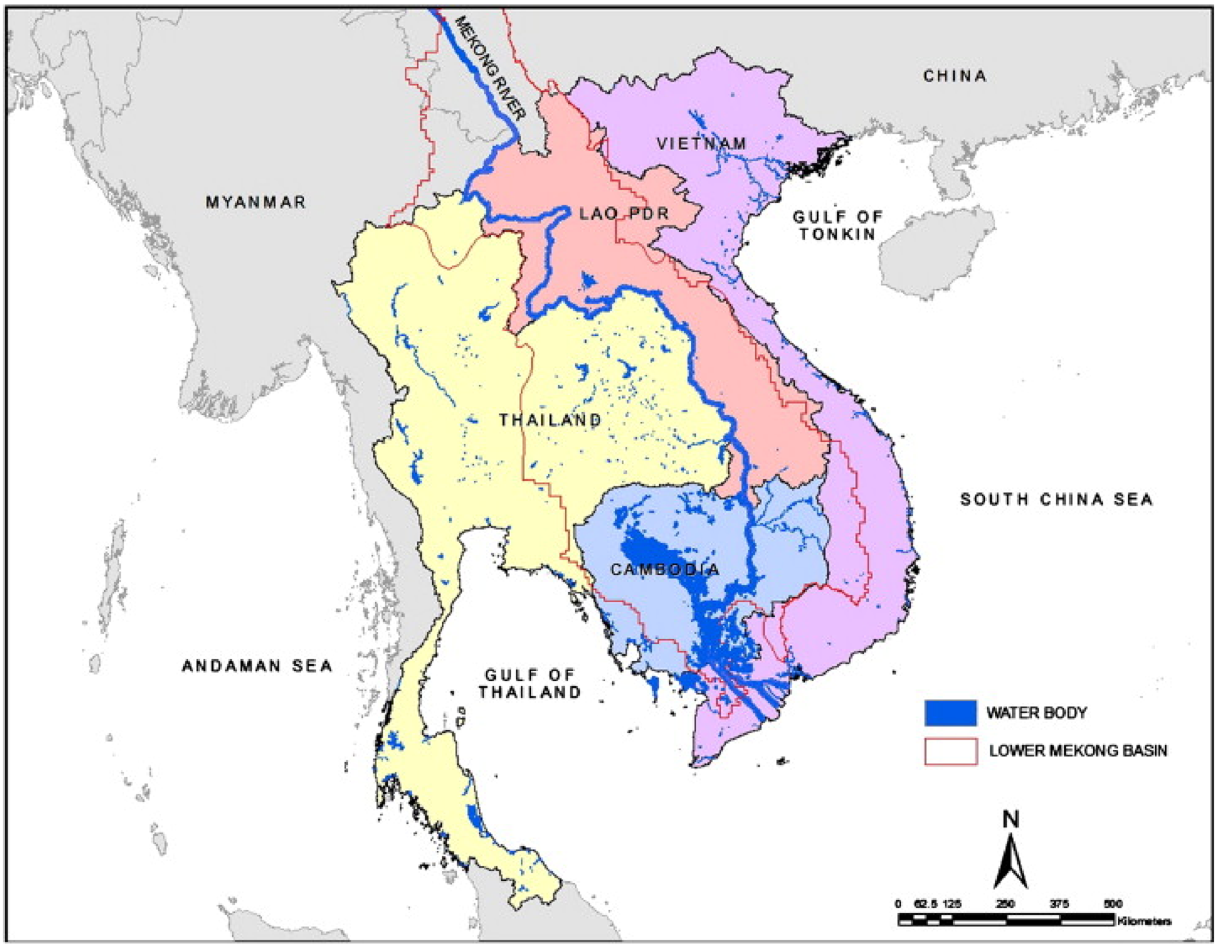

Figure 1.2: Lower Mekong Basin

1.2.1 Hydro climate

The diversity and productivity of the Mekong River Basin is driven by a unique combination of hydroclimatic features that define the timing and variability in water inputs, transport and discharge through the watershed. The combination of two monsoon regimes is the fundamental driver of the Mekong hydroclimate. The Southwest monsoon occurs during the northern hemisphere summer when temperature differences between the land and the Indian Ocean force moisture laden air to precipitate over the Mekong's mountains. The southwest monsoon divides the calendar year into the wet (May – October/November) and the dry (November/December – late April) seasons. During the dry season, air-flow over the Mekong is reversed as a high pressure system over the Asian land mass forces dry continental air flow over the basin, while the northeast Monsoon— originating in the Pacific Ocean— contributes minimal and erratic rainfall because most of the basin lies in the rain shadow of the Annamite mountains (MRC, 2011). A cold climate with snow, which may store precipitation, is only found in the Himalayan plateau (Browder and Ortolano 2000:501), and the monsoon season and tropical climate cause the river to have a particular pulse where the wet season from May to November may account for 85-90% of the total flow of the river (Dore 2003:423). Human life, flora and fauna within the river basin have adapted to this particular rhythm through centuries.

Distribution of rainfall is highly variable throughout the basin along an increasing west-east gradient. Highest rainfall occurs on the western slopes of the Annamites of Lao PDR and Viet Nam, where mean annual rainfall can exceed 2,500mm/year, while the majority of Northeast Thailand and the North-eastern coastal region of the Delta experiences less than 1,200mm/yr. The combined effects of temperature and rainfall lead to strong seasonal reversal in the Mekong moisture budget, which has shaped terrestrial vegetation characteristics. Mekong temperatures are closely correlated to elevation typically averaging between 22–28 °C across the basin, with variance greater within a day (up to 10°C) than between months (up to 5°C). High temperatures result in evaporation rates of 1,000–2,000mm/year (MRC, 2011), which when combined with the seasonal rainfall distribution result in at least 5–7 months of the year under moisture deficit. The deficit is most pronounced in the Khorat Plateau.

1.2.2 Biodiversity

The Lower Mekong Basin is a region of rich diversity in terms of landscapes, biodiversity, ethnicities and cultures. The biodiversity of the Mekong River Basin is of exceptional significance to international conservation and to Mekong country economies and local livelihoods. The region has some 20,000 plant species, 430 mammals, 1,200 bird species, 800 reptile and amphibian species, and 850 fish species. New species are still being discovered each year; between 1997 and 2007 at least 1068 new species were discovered. The Mekong region is ethnically diverse with over 100 different ethnic groups reflecting the diversity of their surrounding natural environment. Many of these ethnic groups have distinct languages, beliefs and cultural practices, including agriculture and animal husbandry, closely associated with the landscape and biodiversity of their area. The Mekong's vast ecosystem and species diversity underpins a wide variety of livelihoods and is the foundation for food security in rural communities. The river basin's resources are vital for its population, as about 85% make their living directly from them (Jacobs 2002:356).

1.2.3 Socio-economic overview

According to Mekong ARCC (2013) the LMB supports around 65 million people, most of whom depend on agriculture and natural resources. The region is in a state of flux: economic expansion and demographic shifts are transforming the economies and environment at a pace and scale never before experienced. Yet, poverty and food insecurity remains entrenched in many parts, even in relatively prosperous Thailand and Viet Nam. Natural resources are essential to rural livelihoods and dependence is likely to increase for the poor in the coming decades. This reliance reflects the acute sensitivity of rural households to adverse weather events, such as floods and droughts, as well as to degradation of the natural environment. While continued economic growth has led to a significant improvement in living standards in recent years, many of the basin's population still live in poverty. The livelihoods and food security of most of the basin's rural inhabitants are closely linked to the Mekong and its waterways.

The river is a source of fish and other aquatic products for food and income, water to grow crops, and a transport route which provides access to markets. This close relationship also means that people are particularly vulnerable if the river and its wetland ecosystems become degraded. The productivity of the Mekong River Basin is dependent on a dramatic process of flooding and recession, which endows the basin wide range of habitats. The timing, extent and duration of floods and the regular inundation of habitats are all important factors in determining the productivity of the river. This ecosystem is fundamental to the viability of natural resource-based rural livelihoods of people living in the Lower Mekong Basin.

The rural poor are heavily dependent upon ecosystem services. This is the case across a range of livelihood activities, including agriculture, fisheries, non-timber forest products, and livestock. Poor rural families in Cambodia, for example, have some 80% of their livelihood activities linked to forest and aquatic resources. Consequently, threats to these ecosystems, such as climate change and major infrastructure projects, have large development and livelihood impacts. In terms of food security, fisheries are the critical source of protein, even in remote upland areas away from large fisheries. In Lao PDR and Cambodia, a surge of infrastructure developments and commercial land concessions are reducing forests, rivers and wetlands in their natural state and the resources and services they provide to rural communities.

There is a general shift towards greater commercialisation of agriculture, with even small-holder subsistence-based households engaged in some form of commercial activity. This trend carries risks, in terms of increased exposure to price shocks and environmental degradation, but also opportunities, such as improved crop varieties. Migration is increasing across the region in search of land, resources and employment. Three main types of migration prevail: (i) rural-urban migration, the most significant type but one that can be highly temporary and seasonal; (ii) transboundary migration, driven partly by a significant diaspora of fellow nationals or ethnicities in neighbouring countries; and, (iii) rural-rural migration, driven by the desire to access natural resources (particularly land in forest areas), and displacement due to land concessions and development projects (Mekong ARCC 2013).

1.2.4 Gender-related issues in the LMB

Rural women assume the primary responsibility for agricultural production in households where men are absent, in addition to their roles of managing the household and caring for children, the elderly and the sick. In general, labour force participation rates for women in the LMB are lower than men. Nonetheless, female participation rates substantially exceed the average of 51 per cent of East Asia and the Pacific, except in parts of the Korat Plateau. The highest rates (above 70 per cent) occur in Lao PDR, Cambodia and the Central Highlands, in areas where most households practice subsistence agriculture (MRC 2003). Women play a central role in the generation of cash income for the household. They are responsible for selling surplus rice, vegetables, non-timber forest products (NTFPs) and livestock. Women's handicrafts are a major source of household income. Women generally manage household money, although men and women share the decisions on expenditures.

Despite their contributions, women tend to work in low-paying, more menial jobs. As a consequence, their overall income levels average only 60 to 75 per cent of men's incomes. Data available for Cambodia and Lao PDR suggest that non-agricultural wage levels for women are about 80 per cent of those of men, except in urban areas where women's income nearly equals men's. They are usually neglected in agricultural extension and other training services which mainly target men in the rural areas. Due to cultural traditions and their lower levels of education, women are thought to be unable to understand or use technology. They therefore have fewer opportunities to receive training to improve their skills as farmers. Women are rarely represented in water user groups and they also have more difficulty in obtaining credit (MRC 2003).

1.3 Project background

The level of knowledge on water resources, land use and livelihoods in the Mekong Basin has been improving rapidly over the past decade. However, knowledge about the linkages between the current crop sector and food security and poverty, together with implications of the expansion of cropping on them under natural resources constraints and their predicted changes occurring in the basin, is still insufficient. Because food security and poverty have multi-faceted links, causes and effects that form current food security and poverty situations need careful analysis. As crop production is a small part of the complex, many assumptions and simplifications have to be introduced to model and assess its roles in the complex. The model has to be realistic enough/worthwhile to mobilise as well as feasible taking into account constraints in data and knowledge.

Particular attention is required on the possible impacts of climate change on the dynamics of the Mekong's water resources. Those dynamics form the basis of the livelihoods of millions of people living in the basin, with those living in the lower reaches of the river in Cambodia and Viet Nam being exceptionally dependent on the basin's water resources.

The MRC Agriculture and Irrigation Programme (AIP) plans to implement a set of activities to monitor the trend of the agriculture sector and to project its future. In line with the programme of AIP, GIZ has offered financial contribution for an assessment of the conditions necessary to achieve the long-term food security and poverty reduction in the LMB under changing climate. Given this offer, the AIP decided to review the current crop sector, food security, and rural poverty as the basis for drawing a pragmatic plan to assess the future of crop production and its implications in food security and poverty.

1.4 Objectives

The overall objective of the study is to facilitate the long-term planning and policy-making in the crop production sector towards a food-secure and poverty-alleviated future of the LMB under climate change.

The conceptual road map for the aforementioned objectives is as follows:

- **Baseline assessment on cropping, food security and poverty**
    - Data Collection relevant to cropping to provide basis for scenario development and analyses
- **Model selection and calibration for production assessment**
    - Selection of statistic models, deterministic crop models and deterministic biomass models
    - Evaluating their performance and calibration with past records in the basin
    - Evaluation of the practical application and feasibility of these models in the basin and their capability of assessing crop production
- **Determination of long-term input constraints**
    - Determination of long-term input scenarios based on constraints identified in baseline assessment process
    - Define future (2025 and 2050) input scenarios for the chosen models based on the available data.
- **Assessment of future production and its spatial distribution**
    - Calculation of crop production and its spatial distribution in the likely future input scenarios.

    - Analysis of climate change impact on crop production based on future climate scenarios

- **Assessment of the conditions for long-term food security and poverty reduction**
    - Assessment of socio-economic implications of future scenarios and analysis of policy implications towards rural poverty alleviation and improved regional food security
    - Analyses of the vulnerability of agricultural systems against climate change and adaptation options based on the identified climate scenarios

The following chapters are the findings of the baseline assessment to draw a pragmatic road map of the aforementioned conceptual steps for the whole LMB. The report covers the result of literature review on food security and poverty, the outcome of the attempts at information collection via office visits, first hand information on cropping practices and rural livelihoods, and lessons from pilot modelling exercises using available crop models.

1.5 Study methods and approaches

The study methods and approaches include the following several steps:

1.5.1 Literature and statistics review

Firstly, an overall review of the LMB in relation to hydro climate, biodiversity, socio-economic assessment, including gender issues, is made. This is followed by a review and assessment of impacts of climate change in agriculture, fisheries, livestock and ecosystems in the region.

1.5.2 Office visits

This was followed by country visits, consultations with the national experts (both from bilateral and multilateral agencies such as FAO/RAPA, FAO Country Offices, UNESCAP and ADB Country Offices) as well national line agency personnel including national agricultural research centres (NARCs) and their regional research centres. During this visit, baseline data of climatic parameters and production data on crops over past years for different agro-ecological zones, were collected wherever it was possible and available. Each country visit also included Ministries/Related Departments/NARC/MRC Focal point and NMCs in the Centre.

These meetings were followed by visits to the provincial and district agricultural development related government offices. During the provincial and district office visits, discussions were held on the major crops grown in the area both in upland and lowland ecology representing rain-fed and irrigated agriculture. Discussions also included food security programmes and plans, and information on major irrigation projects and coordination with central line agencies and departments as well as research centres.

1.5.3 Field visits and Gross Margin Analysis

This was followed by selected farmers' field visits (both upland dry area and low land wet area). The field visit team comprised a consultant, an AIP Programme Specialist, an NMC representative and an Agronomist/Production specialist from the pertinent agency in addition to district agricultural extension specialists and area subject matter specialist. On average, 5–12 farmers participated in providing information on crop production activities. In each site the discussion lasted for an average of 1–2 hours to complete the checklist and information on gross margin analysis of crops grown in the locality. These discussions were held with a representative group of farmers who grow either major cereal such as upland and lowland paddy and/or corn, as well as major livestock feed crops such as corn and cassava for animal feed. In addition, data on livelihood details, economic activities, crop varieties, planting details, soil type/texture, land use statistics, cropping pattern and local adaptation mechanisms to climate change were also collected.

1.5.4 Pilot modelling for work planning

First, crop yield projections for rice, maize, cassava and soybean which are the prime crops covering nearly most of the productive area in the region, were calculated based on the current trends of the yield. This was done with national level data from each country.

Second, rice yield was forecasted using two models namely SWAT and DSSAT. The future climate and agronomic related data of the study area that were used to calibrate the model were collected from the previous research (from Agarwal, 2010 and Babel et al, 2011). Agronomic and crop characteristics related data for crop modelling was retrieved from the experiment which was conducted by the Rice Research Center in Khon Kaen, Roi Et and Ubon Ratchathani.

2. Overview of cropping sector, food security, and rural poverty

2.1 Crop production

2.1.1 Agro ecological zones in the GMS

To capture the interactions and dependencies between agricultural production systems and the ecosystems that support them, Johnston et al. (2009) divided the GMS into five very broad Agro Ecological Zones (AEZs).

i) Deltas and Tonle Sap

Red River Delta, Mekong Delta, Tonle Sap floodplain,1 Chao Phraya Delta and Irrawaddy Delta

The mega-deltas of the Red, Mekong, Chao Phraya and Irrawaddy rivers, and the Tonle Sap floodplain all lie at an elevation below 20 m msl. They represent less than 10 per cent of the total land area in the GMS (~20 Mha), but are home to over a third of the total GMS population of 86 million. The total urban population is around 35 million.

The deltas are the rice bowls of SE Asia, with total production in excess of 46 million tonnes (almost half of the total of 100 million tonnes of rice produced in the GMS excluding Yunnan in 2005). Rice accounts for more than 90 per cent of planted area in Viet Nam and Cambodia, and around 60 per cent of planted area in the Irrawaddy and Chao Phraya.

Different cropping patterns are used in each of the deltaic regions. In Cambodia and the Irrawaddy, the wet-season crop still accounts for more than 75 per cent of the total planting, with substantial (though decreasing) areas of deepwater and floating rice. Irrigated dry-season rice areas are smaller, though increasing as irrigation infrastructure is constructed or repaired. In the Red River Delta, plantings in the two seasons (spring and winter) are approximately equal. In the Mekong Delta, the traditional winter (wet-season) crop has declined to only about 10 per cent of total plantings (0.38 Mha) compared to 1.8 Mha in autumn, and 1.57 Mha in spring. In the Chao Phraya, dry-season planting is only about half that in the wet season—due partly to water availability for irrigation, and also to a choice available to grow high-value wet-season varieties.

Table2.1CharacteristicsofAEZsoftheGMS

	Deltas andTonle Sap	Lowland plains and plateaus	Intensively used uplands	Forested uplands	Coastal areas
Main administrative/ Statistical reporting area in Each AEZ†	KH TonleSap MM Delta TH Central (part)VN Red River Delta VN Mekong Delta	KH North +KH northeast+KH Tonle Sap LA Central +LA South (part) MM Central TH North (part)+TH	CN Yunnan LA South (Bolovens Plateau) TH North MM Hills (Shan Plateau) VN northeast +VN northwest +VN Central Highlands	CN Yunnan LA North +LA South +LA Central (part) MM Hills VNNW	KH Coast MM Coast TH South VN North Central+VN South Central +VN southeast (part)
Area	~8%ofGMSland	~25%ofGMSland	~10%ofGMSland	45%ofGMSland	~12%ofGMSland
Elevation(m)	<20	<250	>250and<3,000	>250	0-2000
Population in millions	86(31%ofGMS)	64(23%ofGMS)	65(24%ofGMS,mostlyinYunnan)	~20(7%ofGMS)	~40(15%ofGMS)
Population	Each hosts a major city. High population density—very high in Red and Chao Phraya. Total urban population~35million.	Moderate density(50—150 persons per km^2, except in K H<10) Area with greatest numbers of poor in TH, LA, probably MM	100-250 persons per km^2 in permanently farmed uplands;	<50 persons per km^2 Dominated by ethnic minorities; high poverty rates (>30%Yunnan and >75% elsewhere) but total number	High-density (>100) exception MM Coast.
Main characteristics	The rice bowls of the major deltas-nearing full production, problems of intensification, flooding, high population density.	Mixed agricultural systems with wet-season rice plus a second dry-season crop (irrigated rice, sugarcane, maize, legumes, pulses, cassava), stubble grazing and plantations (sugarcane, oil crops, rubber, timber and pulp wood).	Intensively farmed uplands with wide range of suitable crops in subtropical—temperate conditions at increasing altitude. Soil erosion, intensification, agro forestry options.	Poorest areas with sloping lands with forest cover, swidden systems and grazing.	Narrow coastal plains rising to coastal ranges at500—2,000m.Short, steep rivers with small watersheds (<50km^2). Mixed production systems, including agro-industrial and tree crops.

Source: Johnston et al. (2009)

†CN=China; KH=Cambodia; LA=Lao PDR; MM=Myanmar; TH=Thailand; VN=Viet Nam.

ii) Lowland Plains and Plateaus

Central Myanmar Plain includes Dry Zone); Central/ Northern Thai Plain; Ian Plateau; Lao Mekong Plains; North and Northeast Cambodia

The lowland plains and plateaus comprise around 25% of the total land area in the GMS, with 23% of the total GMS population (64million). They are characterized by relatively flat low lands and plateaus below 250m, extensively cleared, except in NE Cambodia where a large area of dry forest remains. Agriculture is predominantly rain-fed, with wet-season rice supplemented in the dry season by stubble grazing or a second crop of irrigated rice, irrigated or rain-fed sugarcane, maize, legumes, pulses or cassava. Annual rainfall is generally low (1,200-1,500mm), but higher in Lao PDR and Cambodia (up to 2,000mm).

iii) Coastal Regions

Viet Nam : North Central Coast; South Central Coast; Southeast; Cambodian Coast; Southern Thailand; Myanmar: Tanintharyi; Mon; Rakhine

The coastal zones cover around 10% of the total land area in the GMS with around 10-15% of land area for Thailand, Myanmar and Cambodia but over a third for Viet Nam. They are home to a population of 40 million, i.e.,15% of the total GMS population (almost a third of Viet Nam's population). Population density is generally moderate (>100 persons per km^2) except on the Andaman Coast of Myanmar, which is sparsely populated. The coastal zones have varied production systems, with a high dependence on marine resources and a significant proportion of agro industrial and tree crops (rubber, eucalyptus and other pulp wood).They are characterised by narrow coastal plains (<25 km wide) rising rapidly to coastal ranges at 500-2,000m. Rivers tend to be short and steep, with small watersheds (<50km^2). There are significant coastal flood plains on the Salween (Moulamein) and Rakhine rivers. The average annual rainfall is high in Myanmar (3,300mm) and Cambodia (2,700mm) and lower in southern Thailand (2,300mm) and Viet Nam Coast (average1,800-2,000mm).

iv) Uplands

Areas above 250 m elevation in the region are generally sloping lands with hilly to mountainous terrain interspersed with highly productive river valleys. The total area of uplands is over 1.6m km^2, or 55% of the region; the total population is about 85 million (of which 46 million are in Yunnan). In terms of agricultural production, a distinction can be made between *intensively farmed uplands* (population density >100 persons per km^2*)* and *forested uplands* with shifting cultivation and livestock grazing (population density <100 persons per km^2).

a. Intensively farmed uplands

Yunnan: Northeast and central zones Viet Nam: N*ortheast, Central Highlands*
Thailand: Northern Thailand (Chiang Mai—Chiang Ra i) Lao PDR: Bolovens Plateau
Myanmar: Southern Shan Plateau (Lake Inle)

Intensive agriculture is practiced on upland plains and river valleys, often with terracing for rice. In Yunnan, cultivation is forbidden on slopes greater than 25 degrees. Major food crops grown are rice (irrigated in the river valley upland on slopes), maize, vegetables, wheat and cassava (on marginal lands). Major cash crops include vegetables, flowers (Yunnan, Chiang Mai), tobacco(Yunnan), coffee (Central Highlands, Bolovens Plateau), sugar cane, tea, rubber, pepper, fruit trees, cocoa, and mulberry. A wide range of suitable crops can be grown in the subtropical to temperate conditions at increasing altitudes.

b. Forested uplands—shifting cultivation and grazing

Yunnan: Southern and western zones NW Viet Nam
c. *Northern Lao PDR*
d. *Annamites mountains (Lao PDR and V3)*
Northern, eastern and western mountains in Myanmar

The forested uplands are socioeconomically distinct, with a high proportion of ethnic minorities. There is a very high incidence of poverty: more than 75% of people live below the national poverty line in most are as outside Yunnan with more than 30% within Yunnan. They are physically remote, with poor road access and a very low level of services.

2.1.2 Agro Ecological Zones in the LMB

Van and McNeely (2005) divided the Lower Mekong Basin into five agro ecological zones.

i) **The Northern Highlands** Comprise northern Laos and parts of northern and Northeast Thailand, and is a mountainous region of steep and rugged topography containing only a few sizeable upland plains. It is covered at higher elevations mostly with hill evergreen forest (much of it now replaced by grasslands because of swidden agriculture), and at lower elevations with dry evergreen and deciduous forests with only the valley floors usable for cropping (mainly rice).

ii) **The Annamite Chain** Is a mountainous zone from 50 to 300 km wide which extends some 800 km within the basin in a northwest-southeast direction, and separates the Mekong drainage on the west from the South China Sea drainage on the east. While previously heavily forested, many areas have been cleared for swidden agriculture and are now covered with unproductive grasslands. The opportunities for agricultural development are mostly limited to the tributary valleys.

iii) **The Southern Uplands** Comprise the Elephant and Cardamom mountains separating the Cambodian part of the Mekong Pain from the Gulf of Thailand. The rainfall is very heavy and the region has little scope for agricultural development.

iv) **The Korat Plateau** Comprises Northeast Thailand and adjacent parts of the Lao PDR from Pa Mong south to Pakse. The plateau is a large (550km x 500 km) inter-mountain basin, with thick underlying salt deposits, and much of the area is somewhat dry due to the rain shadow effect of the surrounding mountains. Deforestation was extensive during the last two decades of frontier development and has resulted in recurrent floods and droughts. The plateau's much of the area changed from natural forests to unproductive shrub or grassland.

v) **The Mekong Plain** Is the vast low-lying area (800 km N/S by 600km E/W) traversed by the Mekong River, comprising most of Cambodia, the Mekong Delta and a small part of the Lao PDR. The Vietnamese portion of the Mekong Plain is the most densely populated part of the basin, with rice grown on 50 per cent of the land area. While the present agricultural productivity is substantial, the potentials are excellent for much higher production by means of water resources development.

Rice is the dominant cropping system in the LMB. Farmers in Viet Nam produce three rice crops per year while farmers in Thailand, Lao PDR and Cambodia are producing two rice crops per year.

The areas the study team visited have the following crop systems:

Cambodia

Battambang province has three AEZs, namely; the upland, lowland and flood plain regions. Prominent crops produced in the upland include: upland rice, cassava, corn and soybean. In the lowland rice is the dominant crop with some orchards and vegetables. In the flood area, two crops of rice, namely flood rice and recession rice are grown. The province produces nearly 800,000 tonnes of rice in 290,000 ha, which is 12 per cent of the total rice produced in the country.

Similar issues and patterns were reported in the Kampong Cham Province with dominance of rice production in 165,500 ha during the wet season and 52,000 ha during the dry season, whereas the area occupied by other crops included 124,070 ha during the wet season and 18,420 ha during the dry season. Other important crops grown in the province included Soybean, Corn and Cassava. Black pepper and para-rubber are dominant cash crops in the area. In addition to general needs as identified in Battambang Province, there is also need for fodder, range and pasture development as the province has nearly half a million cattle heads.

Lao PDR

Vientiane Province has a large stretch of mountain range and three large rivers with tributaries which flow into the Mekong River. The Vientiane Plain is one of the six major rice producing plains in Laos. Rice is primarily grown under rain-fed production, although in some areas supplementary irrigation is available. These areas represent a farming system in transition from subsistence to commercial orientation with increasing demand for crops and livestock from Vientiane. Farmers generally grow certain varieties for home consumption (typically sticky rice) and other varieties for sale. Contract farming has been introduced and practised for some years in this province. The Khammouane Province has 60,000 ha to grow rice during the wet season and 10,000 ha during the dry season. There are a number of hydro power projects to be completed and an additional 100,000 ha will be covered by several dam gates. Currently 90 per cent of the produced rice is consumed within the province and only 10 per cent exported outside the province. Rice export policy promotes close collaboration between the government, rice mill groups and farmer groups. The cassava produced in the Province is exported to Viet Nam and China as milled flour. The Province is mainly flat lowland area and there are three remote and hilly districts where private sectors are involved in planting para rubber and cassava.

Savannakhet Province has a target of producing one million tonnes of rice during 2015 in an area of 129,000 ha in the wet season and 30,000 ha in the dry season. Together with Khammouane, Savannakhet is a pilot province for rice policy. Other important crops include maize (both sweet corn and animal feed), cassava, sugarcane, para rubber and groundnut.

Thailand

Thailand is self-sufficient in rice production and is a major exporter of several crops including rice, maize and cassava.

Facing abour shortage farmers in Kalasin Province are shifting to the crops that can be grown from planting to harvesting with machinery. The farmers have started employing water-use-efficiency techniques such as drip irrigation methods. In the Kalasin province, organic rice production is promoted. Yasothone Province has a total farm land of 400,00 ha: 1.5 million ha for irrigated rice and 1.9 million ha for rain-fed area. Para rubber, cassava and sugarcane plantation is growing rapidly. Ubon Ratchathani Province consistes of upland, flat land and flooded areas in the wet season. The major crops grown in this province include rice, maze, peanut, vegetables, Para rubber, sugarcane and cassava.

Viet Nam

The Dac Lak Province is dominated by highland. The rice is cultivated in 80,000 ha, whereas the area occupied by maize is 120,000 ha. Soybean, cassava and cocoa are other crops in the region. Coffee is the most dominant cash crop occupying 200,000 ha. For irrigating rice and coffee, there are 660 companies operating 400 pumping stations with a total capacity of 5–7 million cubic metres of water in 70 reservoirs. Overall, 70 per cent of the cultivated area has irrigation fields. In the dry area, ground water is extracted to irrigate 40,000 ha of coffee in the Province. Over the past decade, more than 10 prominent varieties of improved maize were introduced in the Province. For rice, new and improved varieties occupy nearly 20 per cent of the total cultivated area. Overtime, rice and coffee planted areas have marginally increased and maize area is sustained.

Can Tho Province, for example, is well connected with other provinces and due to its potential for higher agricultural productivity, Government Decree # 45 of 2008 has placed agriculture production improvement as top priority. The total productivity has increased over the span of five years; and in 2012 the average productivity of rice was 5.2 tonne per ha, a 10 per cent increase compared to 2011. Since 2004, there has been an overall 30 per cent increase in the income of farmers. During the same period, 60 per cent of the total rice cultivation has been mechanised and pumping stations have provided assured irrigation facilities. Other dominant crops in the Province include soybean (9248 ha), maize (8769 ha), sesame (4843 ha), sweet potato (571 ha), and soybean (102 ha). In order to get benefits from economies of scale, 2–3 farms are consolidated in one production unit in the province. This allows for mechanisation, increased labour productivity, pest control and reduced environmental pollution.

Tra Vinh Province is the coastal province most affected by climate change. The Province has a total area of 234,715ha out of which agriculture occupies 185,169ha and aquaculture activities occupy another 29,685ha; coconut is the other important crop occupying 20,000ha. The Province is situated in the middle of the Pasak and Mekong Rivers and is affected by tidal wave. The Province has also an intense network of irrigation canals but lacks fresh water during the dry season. The dykes are closed during the dry season to prevent salt water intrusion. The Province also has a large number of livestock with nearly 400,000 pigs and 150,000 beef cattle. The annual harvest from aquaculture amounts to 165,000 tonnes. The province has a protected coastal area of 4,500ha dominated by Sonneratia. The average productivity of rice is 5.51 tonne/ha with the highest yield of 6.23 tonne/ha during winter-spring season and with 5.17 tonne/ha during monsoon season. Major problems faced by the province include: (i) rising sea level, (ii) prevalence of prolonged dry season, (iii) erratic rainfall pattern during wet season, (iv) frequent occurrences of tidal waves, and (v) salinity intrusion in deeper areas. To overcome this, fresh water from the major river is flushed during the rainy season, and during the dry season shrimp farming is practised. Cropping calendars are changed by planting drought resistant and salt tolerant varieties of rice. Also the crops sequences are changed, for example, rice-maize-rice or inter-cropping or relay cropping.

In Xa Hoa Minh coastal Commune in Chau Thanh District of the Tra Vinh Province, the farmers use OM4900 variety of salt tolerant rice which has an average yield of 5.2 tonnes/ha and is grown in two seasons. During the dry season, shrimp is produced with an average harvest of 3 tonnes/ha by 1,610 households in an area of 1,400ha. This pattern started 13 years ago and is still being followed by farmers. The farmer group is connected to the shrimp processing unit and get input and other production loans from the processing units and thus the market is guaranteed. The community feels that they can sustain food security over a longer period both due to increased productivity and changed cropping patterns.

2.1.2 Gross margin

The gross margin represents the percentage of total sales revenue that the enterprise owner retains after incurring the direct costs associated with producing the goods and services sold. The higher the percentage, the more the owner retains on each dollar of sales to service its other costs and obligations. The gross margins for irrigated rice, rain-fed rice, maize, cassava and soybean in the Lower Mekong Basin are calculated using the following equation:

$$\text{Gross Margin} = \frac{\text{Revenue} - \text{Total Cost}}{\text{Revenue}} \qquad (2.1)$$

Gross Margin from literature

Rio et al. (2013) reported per hectare costs of two rice crops in Cambodia to be US$357.60 and US$323.45 excluding labour costs per hectare which are US$192 and US$194. Yields of the rice crops were 2.75 and 2.1 tonnes per hectare and the price per tonne was US$250. Total income generated from the two rice crops were US$687.50 and US$525 per hectare while the gross margins with labour for the two crops were US$137.90 and US$7.55 respectively. For the dry season the cash crop total expense was reported to be US$247.18 per hectare while the labour cost was US$212. Yield of the dry season cash crop was 2.7 tonnes per hectare and the total income generated from the cash crop was US$472.50 per hectare. The gross margin per hectare of the dry season cash crop was figured out to be US$13.33. They also reported the gross margins of various rice varieties including CAR3, CAR4, Phkar Rumdeng, Riang Chay, Phka Rumduol and Phka Romeat. The yield of the above varieties ranges from 3.05 tonnes per hectare for Phkar Rumdeng to 3.97 tonnes per hectare for the Phka

Rumduol variety. Gross margin was highest for Phka Rumduol (US$441.47) while it was lowest for Phkar Rumdeng (US$207.50)

Nhan et al. (2012) calculated benefit cost ratios for two rice crops and the rice-shrimp system in the coastal region of the Mekong delta in Viet Nam. The benefit cost ratio for two rice crops was 0.9 ±0.1 and for the rice-shrimp system the benefit cost ratio was 1.2 ± 0.3.

According to the MRC (2009a) the net returns to rain fed rice are US$102, US$130, and US$37 for Lao PDR, Cambodia and NE Thailand respectively. The net incomes for dry season rice (2nd crop) are US$170, US$245, US$31 and US$304 for Lao PDR, Cambodia, Thailand and Viet Nam delta respectively. For wet season rice (1st crop) the net incomes are US$221, US$251, US$130 and US$344 for Lao PDR, Cambodia, Thailand and the Viet Nam Delta respectively. Similarly net incomes for third season rice are US$435 and 38 respectively for Cambodia and Viet Nam delta. Net incomes for Hybrid Maize are US$162, US$252, US$266 and US$396 for Lao PDR, Cambodia, NE Thailand and the Viet Nam Delta respectively, while net returns to rain fed hybrid maize are US$15, US$86, US$76 and US$172 respectively for Lao PDR, Cambodia, NE Thailand and the Viet Nam Delta.

Table 2.2a: Results of gross margin analysis in literature

	Country	Crop	Yield	Net Income
Rio et al. (2013)	Cambodia	Rice	2.75 tonnes/ha	$137.90/ha
	Cambodia	Rice	2.1 tonnes/ha	$7.55/ha
	Cambodia	Dry season cash crop	2.7tonnes/ha	$13.33/ha
	Cambodia	Various rice varieties	3.05-3.97 tonnes/ha	$207.50/ha-$441.47/ha
MRC (2009a)	Cambodia	Rain fed rice		$102/ha

	Lao PDR	Rain fed rice		$130/ha
	NE Thailand	Rain fed rice		$37/ha
	Cambodia	Dry season rice		$170/ha
	Lao PDR	Dry season rice		$245/ha
	NE Thailand	Dry season rice		$31/ha
	Mekong Delta	Dry season rice		$304/ha
	Cambodia	Hybrid Maize		$162/ha
	Lao PDR	Hybrid Maize		$252/ha
	NE Thailand	Hybrid Maize		$266/ha
	Mekong Delta	Hybrid Maize		$396/ha

Data Source

This study calculated net returns and gross margins from the data obtained in the field visits. Not all upland-lowland areas of the LMB countries grew all the major crops. In Cambodia, for example, during the field visit the team met farmers growing both autumn and spring rice in upland and lowland, maize, cassava and soybean. But in Lao PDR, rice and maize growers were more pre-dominant. While in Thailand, rice, cassava and peanuts were popular in the LMB region; Rice, maize, sesame and groundnuts were grown in Viet Nam on the other hand. Details of the field visits and crops covered in the LMB are given in the following table.

Table 2.2b: Details of country visits and crops covered

Country	Provinces	Crops	Ecology	District/Village	Avg. Farm Size
Lao PDR	Savannakhet	Irrigated Rice	Lowland	Thon Han/Phin	0.56ha/0.5ha
	Vientiane	Irrigated Rice,	Lowland	Chang Village	12000 ha (total)
		Maize	Upland		
	Khammouane	Irrigated Rice	Lowland	Don Kheaw Nue	0.64 ha
Cambodia	Siem Reap	Irrigated Rice	Lowland	Puok (Prasat)	1 ha
	Khampong Cham	Rain-fed Rice, Cassava	Upland	Tboung Khmum/Chamkar Leu	1.5ha/2ha
	Battambang	Irrigated Rice,	Lowland	Rotanak Mondol/Banan	3-5 ha/2-3 ha
		Rain fed rice, Maize, Soybean	Upland		
Viet Nam	Can Tho	Irrigated Rice, Sesame	Lowland	Can Tho (codo)	1 ha
	Tra Vinh	Irrigated Rice, Ground Nut	Lowland	Chau Thanh/ Xa Hoa Minh	1-2 ha
	Dac Lak	Rain fed rice, Maize	Upland		1-2 ha
Thailand	Yasothon	Rain fed Rice, Cassava, Peanut	Upland		1-2[a] ha + 3-4[b] ha
	Kalasin	Rain fed Rice, Cassava	Upland		1-2 ha + 3-4 ha

[a] For rainfed rice
[b] For upland plantation (e.g. cassava, Para rubber, ground nut etc.)

Outcome

The gross margins indicate that the group in Cambodia's Battambang province manages maize production more profitable earning a profit of 61 percent of the invested amount than the groups in Vientiane province of Lao PDR and Dac Lak province of Viet Nam where farmers earn 13 per cent and 6 per cent of the invested amount in maize production respectively. Cassava is also an income-generating crop producing significant revenues for the farmers in the LMB. The per hectare returns to cassava by the studied groups in Kampong Cham (Cambodia), Yasothon and Kalasin provinces of Thailand are US$742.23, US$662.52 and US$230.30 respectively. The gross margins show that the growers earn a profit of 42 per cent, 37 per cent and 17 per cent of the invested amount in cassava production in Kampong Cham (Cambodia), Yasothon and Kalasin (Thailand) respectively. Soybean generates a net profit of US$605.32 per hectare with a gross margin of 66 per cent in the studied area of Battambang province in Cambodia.

Net returns to rain fed rice range from US$69 per hectare in Dac Lak province, Viet Nam to US$663 per hectare in Kalasin province of Thailand. The gross margin for rain-fed rice in the Dac Lak province of Viet Nam is only 7 per cent while for Kampong Cham (Cambodia), Khammouane (Lao PDR), Yasothon and Kalasin (Thailand) rain-fed rice gross margins are 60 per cent, 58 per cent, 34 per cent and 51 per cent respectively.

In the irrigated region of Siem Reap and Battambang provinces in Cambodia, rice growers produce two rice crops per year (spring rice and autumn rice) while in Can Tho and Tra Vinh provinces in Viet Nam farmers are producing three rice crops per year (winter-spring rice, summer-autumn rice and autumn-winter rice). The net returns to irrigated rice in the LMB range from US$25 per hectare for autumn rice in Battambang (Cambodia) to US$2,090 per hectare in Vientiane (Lao PDR). The gross margin is the lowest for autumn rice in Battambang province in Cambodia (only 4 per cent) while the highest gross margin (66 per cent) is recorded for winter-spring rice in Can Tho province in Viet Nam.

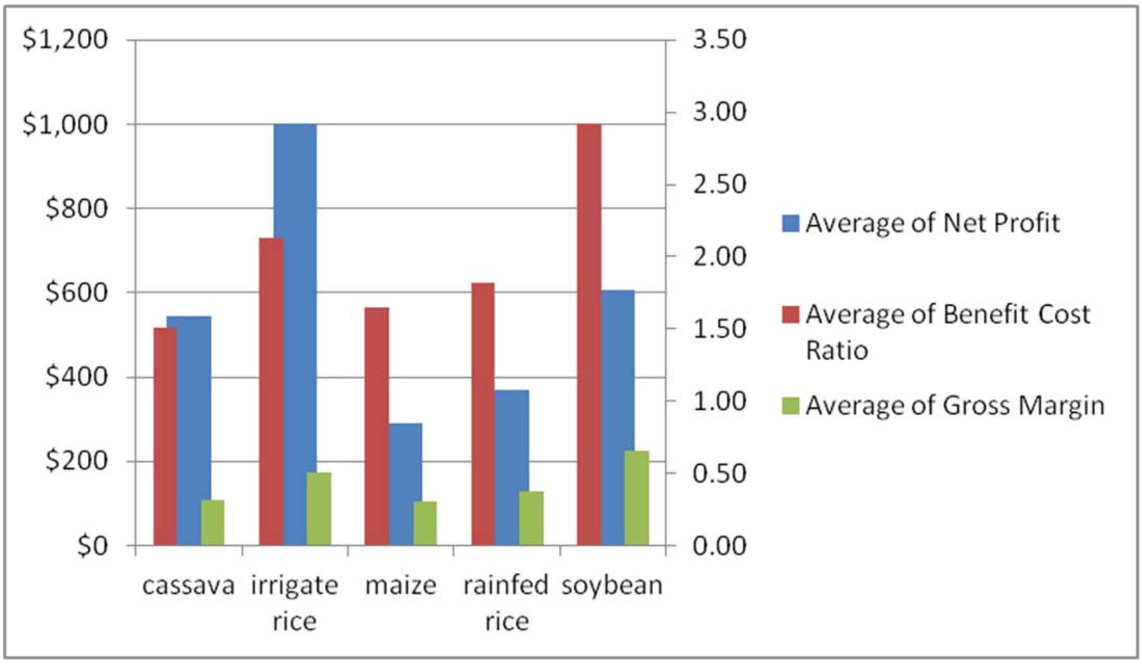

Figure 2.1: Average net profit, benefit cost ratio, and gross margin

Above all, significantly higher net income values than those reported in literatures were found in both rice and maize production. This suggests the continued progress of agricultural intensification or productivity gain in these crops.

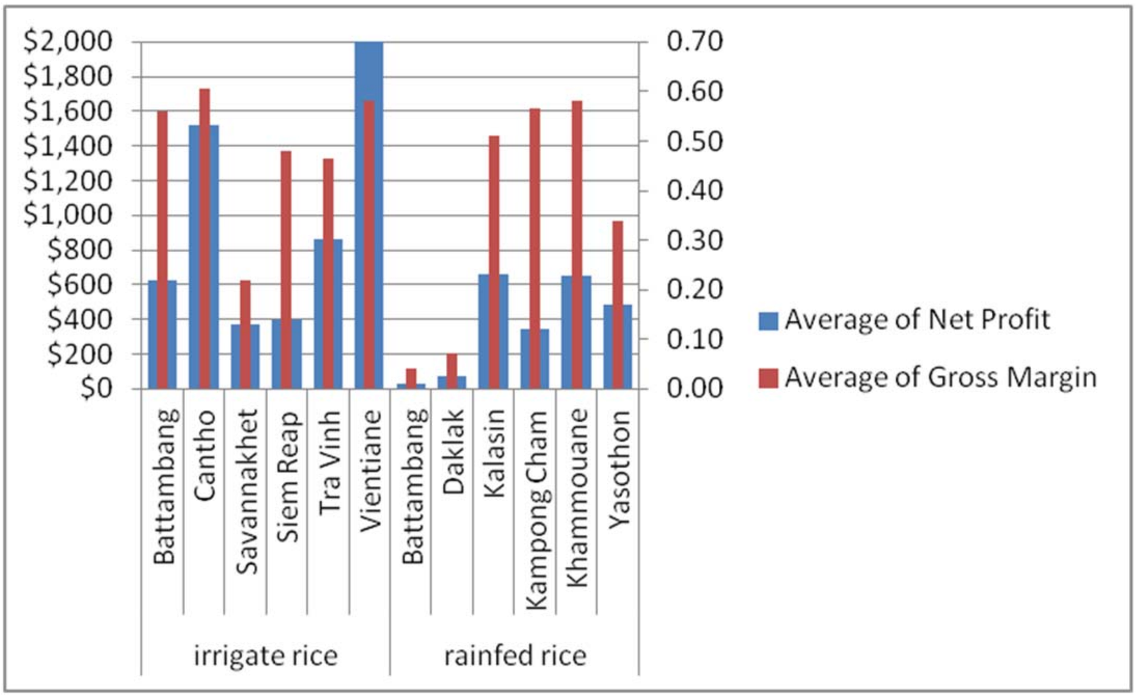

Figure 2.2: Net profit and gross margin in rain fed rice and irrigated rice

Though irrigated rice was found most profitable in average among the studied crops, net profit and gross values are significantly different in each site. Some groups who grow irrigated rice make lower profits than those who raise rain fed rice in other areas. Upland crop systems are making almost the same profits with the lower group of irrigated rice, too.

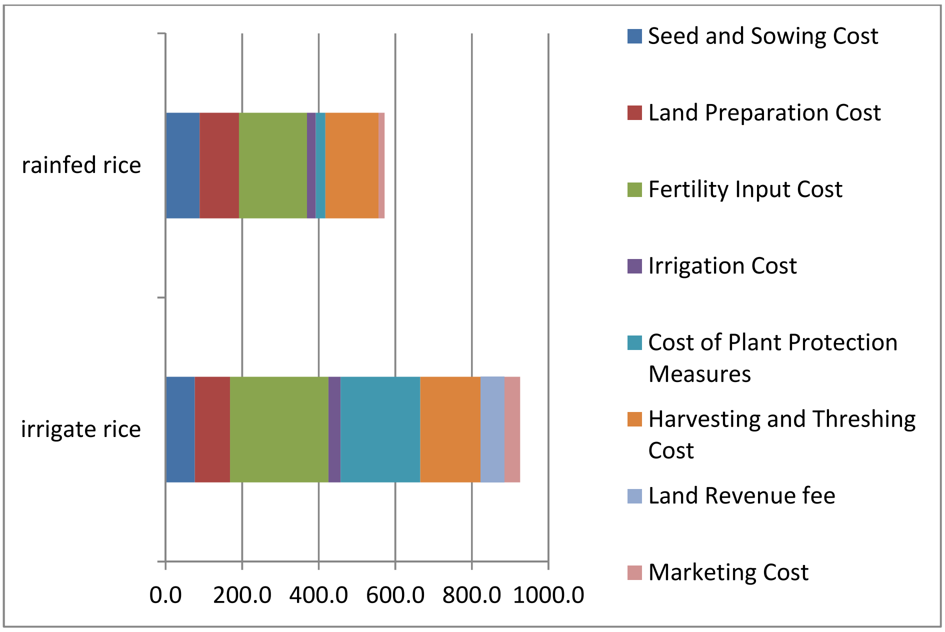

Figure 2.3: Cost structure of rain fed rice and irrigated rice

When looking into the average cost structure between rain fed rice and irrigated rice, cost for crop protection and fertility inputs are significantly higher in the irrigated rice. Higher fertiliser use infers that farmers invest more for irrigated rice because drought risk is lower. Higher cost of crop protection, i.e. chemical and herbicide use, also suggests higher rates of broadcasting, which becomes a norm in labour short areas. The rain fed rice growers in Khampong Cham and Battambang in Cambodia had recorded a higher yield of rice at 2.5 tonne/ha, however, the gross margin in Battambang was far less due to higher costs for harvesting and threshing, seed and fertiliser use in addition to lower price of paddy rice immediately after harvest. The farmers in Battambang have incurred three times higher cost of harvesting due to continuation of manual harvest as compared to Khampong Cham which has more efficient machine harvesting and threshing. The lower price of paddy rice in Battambang suggests forced sale of paddy by the farmers immediately after harvest. The average cost for plant protection reflects the very high protection costs in the Mekong Delta. Higher costs for land fee and marketing in irrigated rice suggest that irrigated rice farmers tend to expand operation and ship more rice to market while rain fed rice farmers are more likely in a subsistence condition. One rather paradoxical issue found from the comparison of the two groups is the cost of irrigation. Although the difference between the two groups is whether they are irrigated or not irrigated, actual costs paid for irrigation were almost the same and negligible in both groups. This leads to two suspicions. Irrigation fees in public irrigation schemes are very low and the costs farmers have to pay for private water sellers to secure the standing crop during a drought are rather high. The details of gross margins analyses are given in Annex 1.

2.1.3 Production trend

This section presents the projected yields of the selected crops for 2025 and 2050 in the LMB countries with the current trends and projected yields of rice, maize, cassava and soybean in Thailand for 2025 and 2050 under climate change using an econometric model. The gross margins of selected crops in different agro-ecological zones in the LMB are also provided, and some national and provincial food security and poverty conditions and issues are discussed in the later part of this section.

Yield projections are calculated for rice, maize, cassava and soybean in Thailand, Lao PDR, Cambodia and Viet Nam using national level data. These projections are based on the trend curves in the yield of the crops. The national level data for these projections are obtained from FAOSTAT for the period of 1990 to 2012 (Annex 2).

Rice

Rice yields in four countries of the LMB are projected with the past trends in the yield from 1990 to 2012. Rice yield in all the LMB countries show an increasing trend by 2025 and 2050. In Thailand the rice yield is expected to increase by 24.57 per cent in 2025 and by 62.86 per cent in 2050 against the yield in 2012.

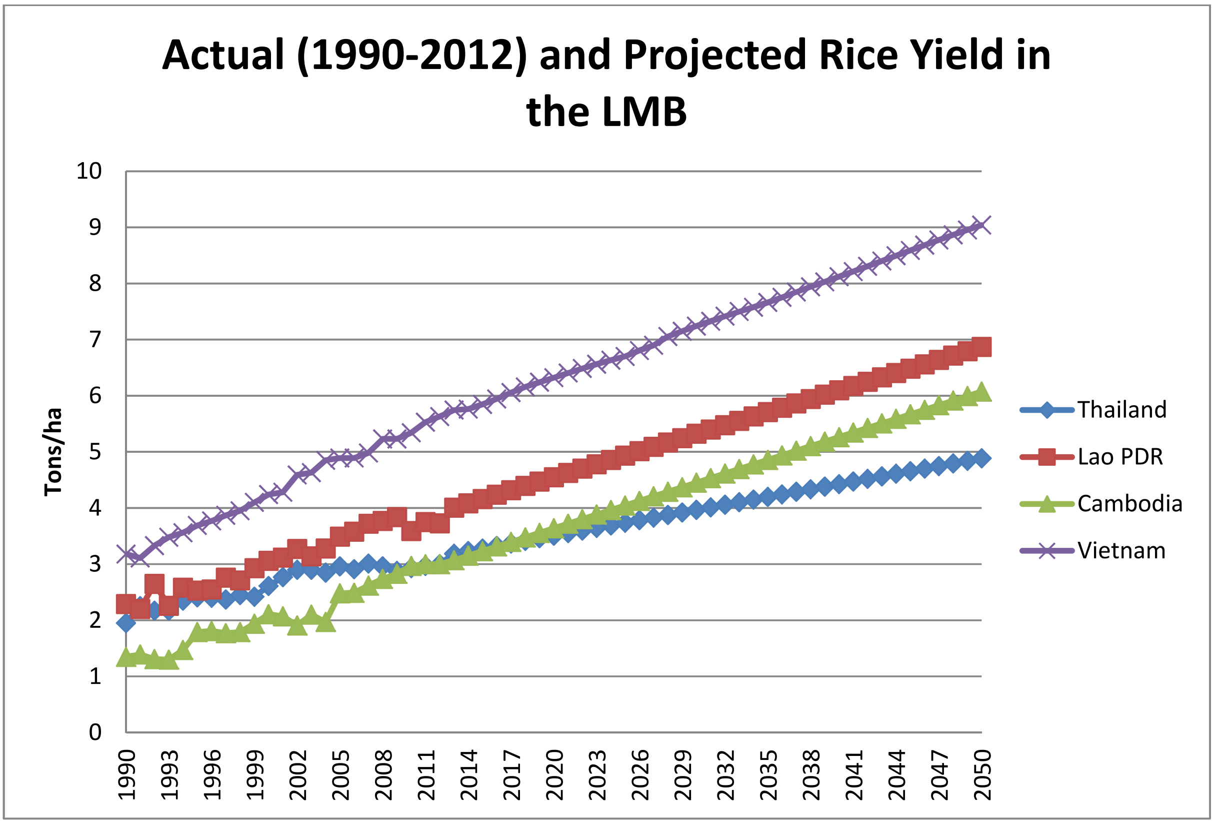

Figure 2.4: Actual (1990-2012) and Projected Yields of Rice in the LMB

In Lao PDR the yield of paddy rice is expected to increase by 32.32 per cent in 2025 and by 84.19 per cent in 2050. Similarly, in Cambodia, yield of rice will increase by 34.85 per cent in 2025 and by 102.53 per cent in 2050 while in Viet Nam rice yield is expected to increase by 19.01 per cent in 2025 and by 60.56 per cent in 2050.

Maize

Based on the trends, maize yield is expected to increase in all countries of the LMB by 2025 and 2050 (as shown in figure 2.5). In Thailand, maize yield will increase by 22.82 per cent in 2025 and by 67.09 per cent in 2050 against the yield in 2012. Similarly, the yield of maize in Lao PDR is expected to increase (with current trends) by 32.88 per cent in 2025 and 114.23 per cent in 2050. Maize yield in Cambodia is expected to increase by 109.26 per cent in 2025 and 225.66 per cent in 2050 while in Viet Nam the yield of maize is expected to increase by 41.64 per cent in 2025 and 118.02 in 2050.

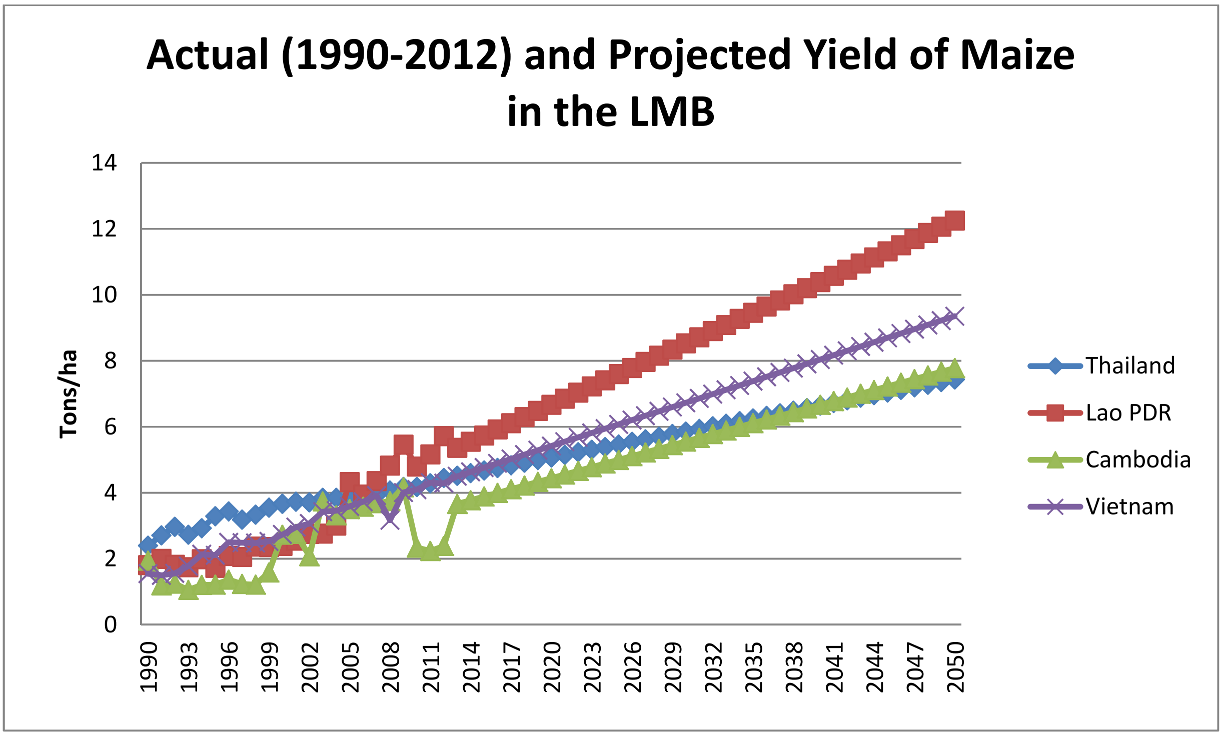

Figure 2.5: Actual (1990-2012) and Projected Yields of Maize in the LMB

Cassava

Based on the trends, cassava yield is expected to increase in Thailand, Cambodia and Viet Nam while in Lao PDR the yield is expected to decrease by 2025 as against the yield of 2012. Yield of cassava in Thailand is expected to increase by 46.93 per cent in 2025 and 100.83 per cent in 2050 as against the current yield of 2012. In Lao PDR, the yield in 2025 is expected to be 8.77 per cent lower than the recorded yield in 2012 based on the trend and increase by 29.07 per cent in 2050. Cassava yield in Cambodia is likely to increase by 58.38 per cent in 2025 and by 160.98 per cent in 2050. Similarly, in Viet Nam the yield is expected to increase by 42.03 per cent in 2025 and by 117.69 per cent in 2050 as against the yield in 2012.

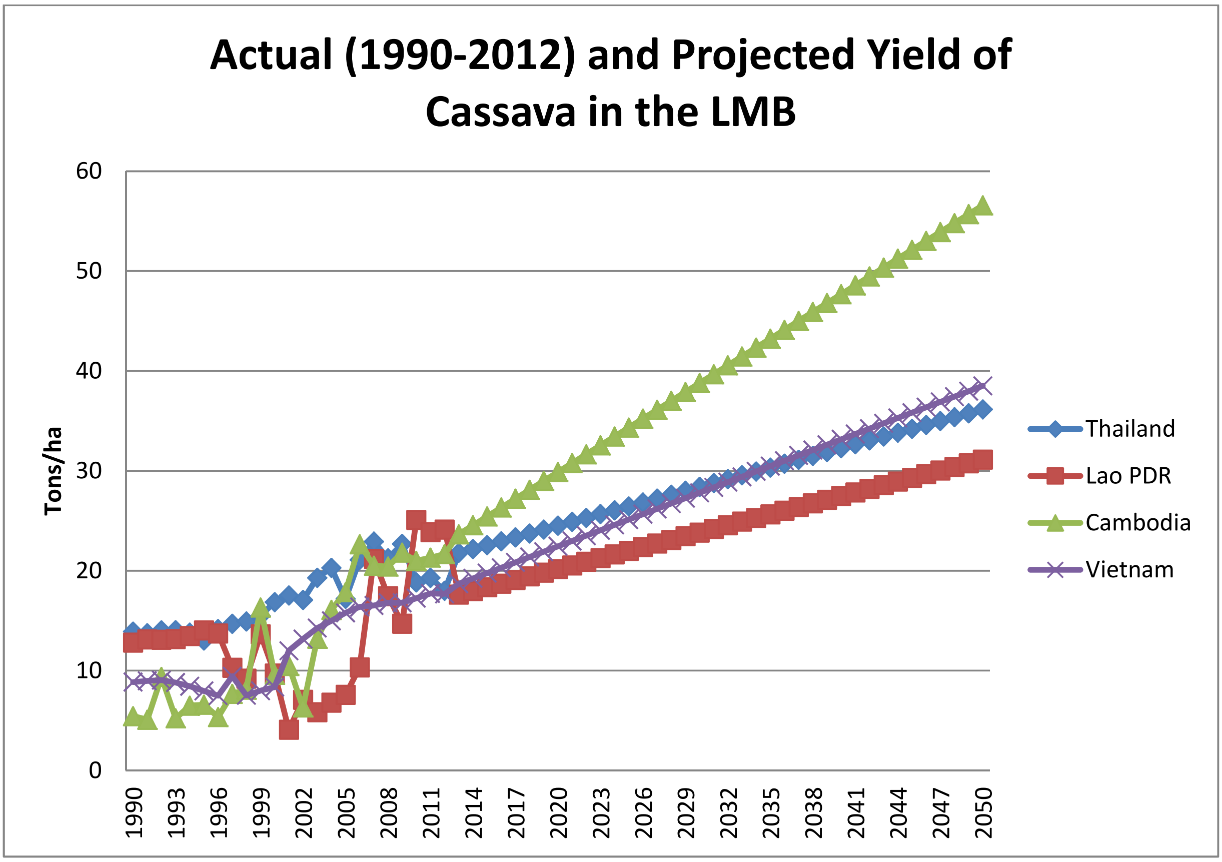

Figure 2.6: Actual (1990-2012) and Projected Yields of Cassava in the LMB

Soybean

Projections based on the trend of soybean yield show increase in the yield in Thailand, Lao PDR and Viet Nam by 2025 and 2050 while a decrease in the yield in Cambodia by 2025 and 2050 against the yield of 2012. An 11.05 per cent increase in the yield of soybean is expected in Thailand by 2025 and by 2050 the yield is likely to increase by 39.24 per cent as against the base year (2012) yield. In Lao PDR, the soybean yield is expected to increase by 16.65 per cent in 2025 and by 71.69 per cent in 2050 with the current trends. Records of soybean yield in Cambodia have a declining trend. Projection based on the trend shows expected decrease by 33.08 per cent and 59.87 per cent in 2025 and 2050 respectively. In Viet Nam, the yield is likely to increase by 39.98 per cent and 99.69 per cent by 2025 and 2050 respectively.

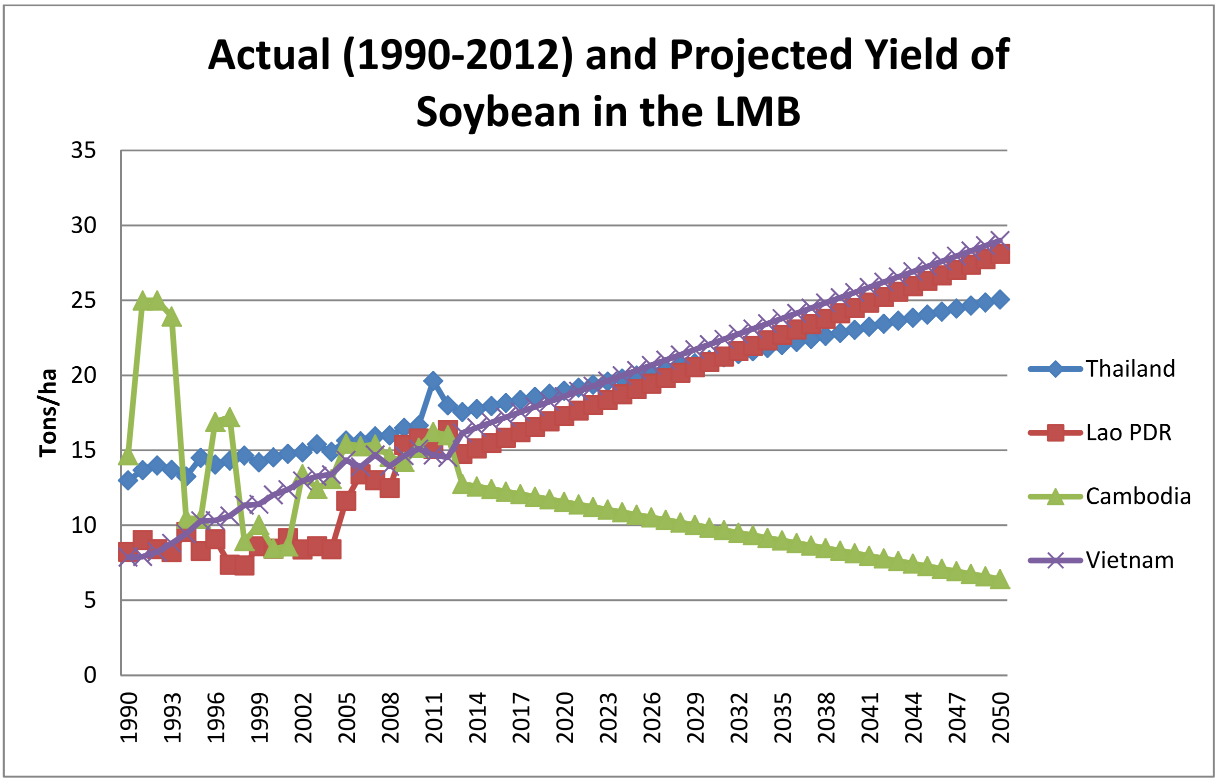

Figure 2.7: Actual (1990-2012) and Projected Yields of Soybean in the LMB

2.1.4 Developments in the field

The income for the rain fed upland crops is currently very low as reflected by small gross margin of only US$25 in Battambang province during the team's field visit. This is a reflection of the low input, low yield farming system employed by farmers not only in Cambodia but also in Lao PDR and NE Thailand. Crop yields are projected to be significantly higher than currently achieved if historical trends continue.

Change in variety

Part of the improvement will be a result of newly released higher yielding varieties. For achieving higher yield, in addition to the adoption of higher yielding varieties, spending has to be increased in fertiliser along with crop protection (usually IPM measures) particularly in Lao PDR, Cambodia and NE Thailand. The development of OM series of high input response varieties by the Mekong Research Institute in Can Tho and Tra Vinh Provinces of Viet Nam is a good example of such steps already being initiated.

Chemical application

Pesticide applications are low in Cambodia, Lao PDR and NE Thailand because of the low degree of intensive agriculture. In Lao PDR, the Ministry of Agriculture, Forestry and Fisheries is touting the export of large quantities of organic rice at premium prices indicating the government will discourage the heavy use of pesticides in that country, but it will be difficult to prevent farmers from protecting their higher yielding crops. Herbicides will be extensively used in irrigation areas as farmers convert from transplanting to direct seeding in an effort to reduce labour costs. The use of insecticides and fungicides will increase significantly on rain fed and irrigated wet season crops for each country except Viet Nam where usage may have already peaked. Dry season use should remain fairly stable across all countries for the same reasons (MRC 2010a).

Mechanisation

There is considerable scope for mechanisation in Lao PDR and Cambodia while Thailand and Viet Nam have already begun mechanising their production activities. The number of days spent on a hectare of rice could be reduced significantly through mechanisation if the area under irrigation does not change (MRC 2010a). Labour-saving machinery will become increasingly important in farming systems, particularly in those of Lao PDR and Cambodia. Mechanisation will reduce labour costs and will improve the timeliness resulting in higher efficiency. Labour shortages have encouraged a high degree of mechanisation in NE Thailand farming areas (Kalsirisilp and Singh 2001). During visits to farmers' fields in Kalasin and Yasothon Provinces, the consulting team was apprised of extensive use of small tractors, seeders and harvesters for the production and harvesting activities of paddy and peanut. There is little scope for extra mechanisation in these areas and labour efficiencies in the future will most likely result from farm area consolidation. The Mekong Delta in Viet Nam is also highly mechanised. The introduction of a stripper in Viet Nam will improve efficiency further but the farm size needs to increase to over 1ha before this type of machine will become economically viable (Anonymous 2007). They are already fully functional in the lowland paddy growing farms in Tra Vinh and Can Tho as observed by the consulting team during the field visit. In Can Tho province, for example, 65 per cent of the total cultivated area has been mechanised both in production and harvesting by creating a specialised service provider in order to benefit from a larger economy of scale and operation. The government has provided a 100 per cent subsidy support for the import of harvesting machines and a 60 per cent subsidy for locally manufactured machines. For effective use of machines, 2–3 farms of 1.00–1.5ha size are consolidated as one management unit.

Combination

The 3 decrease (seed cost, fertiliser use and water use reduction through improved efficiency), 3 increase (increased production of green mushroom and commercial products and increased insect-pest resistance) programmes combined with high yielding and high quality varieties of rice increases productivity. Developing new flood resistance and drought tolerance varieties will have tremendous impact on increasing productivity in a sustainable manner. Similar activities were also observed in North-East Thailand and Battambang region in Cambodia.

To counter low productivity and low return from rice, the provincial agriculture development offices in Battambang and Siem Reap provinces, introduced drying seed technologies in order to increase seed vigour and rice productivity. There is also effort and priority of Cambodian government linking minor irrigation schemes to major irrigation development projects. In Tra Vinh coastal area, farmers have started to grow two crops of rice during autumn and monsoon but during the dry season the farmers grow shrimp, due to salt water intrusion.

Crop diversification

The current cropping patterns, particularly in Viet Nam, may reduce the yield of rice crop in the long run as the crop-specific pest and diseases will increase over time. Controlling pests and diseases will require more efforts and hence will increase the total cost of production and reduce the net revenues. Continuously growing the same crop will tend to exploit the same soil root zone, which can lead to a decrease in available nutrients for plant growth and to a decrease in root development.

Viet Nam's government has already planned to change the rice-rice-rice pattern to rice-shrimp-rice on 0.1 million ha coastal farming areas. During the field visit it was observed that in the upland area of Dac Lak, farmers have already started growing catch crop; i.e. ground nut and sesame. Similarly, the upland farmers of Kalasin and Yasothon in Northeast Thailand have changed to organic farming practices, and catch crop such as sesame and peanut are getting popular.

Irrigation development

The area under irrigation has expanded gradually in all four LMB countries. Most of the installed irrigation infrastructure is found in Northeast Thailand and the Viet Nam Delta. A recent assessment of irrigation in the LMB recorded almost 15,000 individual irrigation projects, varying from small- to large-scale and from gravity- to pump-fed irrigation (MRC 2009b). The total area under irrigation in the LMB is estimated at four million hectares, comprising 3.5 million hectares in the wet season, and 1.2 million hectares in the dry season. About 1.5 m hectares is used to grow a third crop (Mekong ARCC 2013).

Since 1990, with grants and loans from development partners, the Government of Cambodia has made significant investments in irrigation development. Dry-season rice production in Lao PDR is fully dependent on irrigation water supplies and has only become significant since the installation of more than 7,000 diesel and electric pumps in the mid-1990s. According to national statistics, the achievement of the self-sufficiency target was mainly due to the increase in wet-season production. Irrigation is also used for vegetable production. Over the past 10 years the area of irrigated agriculture in Northeast Thailand has been fairly static and, despite large investments, actual water usage remains low outside the wet season. Irrigation in the Viet Nam Delta is used to grow rice, upland crops and fruit trees. In the Central Highlands, production is far less, with an area of irrigated rice estimated at only 141,684 ha in the wet season and 76,184 ha in the dry season (Mekong ARCC 2013).

During the field visit by the consulting team along the Chi River Irrigation project in Ubon Ratchathani province, it was observed that nearly 126,000ha of new areas are now under irrigation. But these areas are inundated during the monsoon season by flood, and only winter crops can be irrigated. Therefore, flood control during monsoon season is a major challenge for the irrigation department.

2.2 Food security

2.2.1 Overview

Great progress has been made to reduce poverty and food insecurity across the region. The Mekong River Basin is one of the world’s most significant food sources, particularly for the growing urban population of the Greater Mekong Sub-region. It provides the staple diet for approximately 300 million people and can, with care, produce much more as demand increases. On the other hand, GDP is projected to grow at a long term rate of about 4.5% annually, and food production in the LMB will need to increase by an estimated 25% during the next 20 years to keep pace with the expected demographic, income and dietary changes (Islam, N, 2008).

Rice is the major crop occupying more than 10 million ha of the Basin’s 18 million ha of cultivable land, but 60% of the rice field is rain-fed. Pure rain fed rice crop yields in these countries are currently around 2.3 tonnes/ha during the wet season, increasing to about 2.8 tonnes/ha with supplementary irrigation and to between 3.1 and 3.9 tonnes/ha during the irrigated dry season (MRC 2010b). These figures suggest substantial space for increased production as well as changing crop choice.

Growth in income and staple food production masks the vulnerability to regress, particularly following strong external shocks like extreme weather events to rural populations. Food security involves the availability, sustainability, accessibility and safety of nutritional food requirements. When all people at all times have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life, food security exists (FAO 2008). Even households that have moved beyond a marginal existence and possess productive assets, such as irrigation infrastructure and farm machinery, have much to lose from reduced access to natural systems and resources. Seventy-five per cent of the population living in the Basin earn their living from agriculture and fisheries. Balanced and efficient land and water use is essential to long-term food security in the Mekong River Basin. The inland capture fishery production in the LMB forms, together with rice, the basis for the food security of the rural population. Fish is the single most important source of animal protein for this population, and a very important source of income as well. The common property nature of the resource base of the fishery sector is spawning increasing conflicts inside the sector between the different actors as well as threats from other economic sectors using partly the same resource basis.

For the economically and socially most vulnerable strata of society, access to common property resources constitutes a last safety net in subsistence conditions. Discussions on food security have broadened from resource-based approaches (predominantly land and water) to a more integrated approach that links natural resource management with livelihood options and household levels of nutrition. All countries contain particular groups whom remain chronically poor, or are vulnerable to falling into poverty and food insecurity.

Food insecurity in all LMB countries is concentrated mainly in remote mountain areas with low levels of rice production. In general, ethnic minorities have higher levels of poverty and food insecurity. There is a strong correlation between food insecurity and poverty, but it is not simple: households with very low income and expenditure may have higher food security due to access to wild resources; even households with reasonable income may not be able to afford to purchase food if prices rise, as they did in 2008. Food shortages are a result of a range of factors, including local crop failures, lack of access to markets, and poverty or lack of funds to buy food even when it is available.

2.2.2 Cambodia

GDP growth in Cambodia has been strong in recent years averaging an annual 9 per cent growth before the 2009 global downturn (ADB, 2009a). In 2009 the economy contracted by 2 per cent (ADB, 2009a). Despite its robust economic growth, Cambodia remains a poor country with more than 25 per cent of the population living on less than US$1.25 per day as of 2007 (ADB, 2009a). The UN Development Programme ranked

Cambodia 131 of 177 countries, placing it among the poorest countries in the world (ADB, 2009e). Cambodia was hit much harder than Lao PDR by the 2007-2008 food crises with the prices of rice and fertiliser doubling within a year while meat and fish prices rose a reported 30 to 60 per cent (ADB, 2009e). The High Level Task Force for the Global Food Security Crisis, HLTF, (2009a) estimates that the rises in food price triggered an increase in the number of food-insecure people in the country by more than 50 per cent (up to 2.8 million people). The impact of food price rises is particularly acute in Cambodia where food accounts for 60 to 70 per cent of rural household expenditures with rice alone accounting for 40 to 50 per cent (HLTF, 2009a).

The lack of storage capacity, inadequate transportation linkages and poor access to market information are major barriers to the improvement of agricultural yields and food security in the country (HLTF, 2009a).

In Cambodia, as in Lao PDR, approximately 80 per cent of the population lives in rural areas (FAO, 2011a). Also like Lao PDR, Cambodia's exports of maize have grown substantially over the last decade. In the early 2000s maize was not a significant export but by 2008 Cambodia had exported more than 311,000 tonnes, making it the primary commodity export by value (FAO, 2011c). Other major exports include rubber, palm oil and soybeans all of which are significant imports of the PRC (FAO, 2011c). In 2009 agricultural output expanded by approximately 4 per cent with favourable rains cited as a primary cause (ADB, 2010). Aquaculture and marine fishing also increased substantially (ADB, 2010). The ADB estimates that in 2010 agricultural output will likely increase by approximately 4.7 per cent (ADB, 2010).

2.2.3 Lao PDR

Food security is a concern in Lao PDR where the FAO estimates that approximately 19 per cent of the population is undernourished (FAO, 2011b). Almost 80 per cent of the population live in rural areas (ADB, 2010). Although the country has experienced strong economic growth since 1990, approximately one-third of the population remains below the national poverty line and as of 2002, 44 per cent of the population was living on less than US$1.25 per day (ADB, 2009a). According to World Bank data, although growing, the GDP per capita in the country is US$1,270 (GNI Attras method, World Bank, 2012).

In 2009, the UN HLTF reported that the impact of surging food prices in 2007-2008 was less severe in Lao PDR than in other countries in the region (HLTF, 2009b). The primary staple food in the country, domestic sticky rice, is not imported and thus less vulnerable to international price fluctuations. However other factors have contributed to the increase in the price of rise in the country such as severe flooding, a major outbreak of pests, US dollar inflation and rising fuel prices. Therefore, despite the barrier from the impact of global food prices, the poorest segments of the population remain extremely vulnerable to domestic price fluctuations (HTLF, 2009b).

Within Lao PDR, agriculture accounts for approximately one-third of GDP while employing over 70 per cent of the workforce (ADB, 2010). ADB (2010) reported that in 2009 the agricultural sector grew by an estimated 2.3 per cent. Increasing demand in the PRC may offer opportunities to Lao PDR to ramp up agricultural production. Such demand has already resulted in a sharp rise in feed-maize exports destined to the PRC (World Bank, 2008). Maize and coffee are the two primary export commodities of the country (FAO, 2011c). Maize exports in particular have grown rapidly over the last decade rising from less than 1,000 tonnes in 2000 to more than 126,000 tonnes in 2008 and valued at more than US$14 million (FAO, 2011c).

Millar and Photakoun (2008) find that Lao PDR is in a favourable position to capitalise on rising demand for meat in neighbouring countries, particularly PRC. The authors note that livestock plays a major role in the economies of rural communities and increased livestock production and demand for livestock products may significantly contribute to poverty alleviation in the country.

Table 2.3: Distribution of Household according to food consumption patterns

Province	Food Consumption Groups			HH Dietary Diversity Ranges		
	Poor	Borderline	Acceptable	<5	5 to 8	>8
Vientiane. C	0.0%	3.4%	96.6%	3.7%	59.0%	37.4%

Phongsaly	0.0%	2.5%	97.5%	7.4%	82.5%	10.1%
Luangnamtha	1.1%	2.6%	96.3%	7.0%	61.1%	31.8%
Oudomxay	0.9%	4.7%	94.4%	18.5%	69.3%	12.2%
Bokeo	0.0%	22.1%	77.9%	7.7%	67.8%	24.5%
Luang Prabang	3.8%	11.4%	84.8%	51.7%	44.2%	4.1%
Huaphanh	5.7%	27.6%	66.7%	41.3%	54.8%	3.8%
Xayabury	3.3%	6.4%	90.3%	11.7%	72.7%	15.6%
Xiengkhuang	10.2%	32.9%	56.9%	34.1%	50.3%	15.7%
Vientiane	1.1%	3.5%	95.3%	5.4%	64.9%	29.7%
Borikhamxay	0.8%	1.2%	98.1%	7.1%	53.8%	39.1%
Khammuane	0.0%	4.0%	96.0%	19.3%	69.1%	1.6%
Savannakhet	0.4%	2.3%	97.3%	14.4%	68.2%	17.4%
Saravan	2.9%	18.6%	78.5%	26.8%	66.3%	6.9%
Sekong	22.6%	40.4%	37.0%	70.8%	29.2%	0.0%
Champasack	1.3%	2.7%	96.0%	5.1%	69.7%	25.1%
Attapeu	3.8%	11.4%	84.8%	55.9%	41.4%	2.8%
Total	2.3%	8.9%	88.8%	19.0%	63.2%	17.9%

Source: Govt. of Lao PDR, Risk and Vulnerability Survey 2012/13

Food Availability

Lao PDR cultivates and produces an abundance of foods, complemented by a wide range of animal and plant foods sourced from its forests, rivers, lakes and mountains. In common with other Southeast Asian Nations, the prevailing agricultural priority at both national and household level is rice production, with glutinous rice making up 85 per cent of total rice consumption (FAO and WFP 2011). In 2010, Lao PDR harvested 3.07 million tonnes of rice; generating surplus estimated in excess of 300,000 MTs (Thadavong 2012).

In terms of trends in the agriculture sector, the past ten years have seen a shift from subsistence-oriented agriculture to market-focused agriculture. This transition to commercial agriculture is relevant to food security in a number of ways, with implications in terms of land access, tenure and access to NTFPs (Non-Timber Forest Products). Nevertheless, overall availability of food (per capita availability) at the national level has not been adversely affected: harvest yields and livestock populations have increased steadily over the past decade (Govt. of Lao 2013). According to 2010/11 Agricultural census notes, 30 per cent of Lao PDR's 782,000 agricultural households produce crops mainly for sale (ACO 2012). With this shift in agriculture, increased production of cash crops for export (including cassava, coffee, tea, maize, rubber and sugar cane) has been a major factor in the agricultural context of Lao PDR.

With Lao PDR positioned between two major food exporting nations (Thailand and Viet Nam) formal and informal imports are an important feature of food availability, with imports used to cover temporary shortfall, especially in areas proximate to the borders (FAO and WFP 2011). However, information on informal imports is incomplete, with the result that the role of the informal sector in the overall food availability profile of the country is not fully understood. In terms of formal imports, the total rice imports estimated for 2011 is in the order of 30,000 MTs, equivalent to one per cent of total domestic production (FAO and WFP 2011).

Access

Economic Access

The continued annual GDP growth of 6 to 8 per cent has translated into increases in per capita GDP. In 2010, per capita GDP stood at US$1,176, up from US$326 a decade earlier (World Bank 2012). Even so, poverty remains an important factor, with 3 per cent of the population living on less than US$1.25 per day (UNDP 2011). Poverty and food insecurity have long been correlated because poverty lines derive in part from the cash equivalents needed to purchase the minimum calories required per person per day (usually estimated at 2,100 Kcal). Food insecurity tends therefore to be more prevalent among the poorer population. In Lao PDR, determinants of poverty include geographic remoteness, high altitudes, recurrent exposure to disasters and ethnic status (MPI 2010).

Food access is also influenced by seasonality. Areas without all-weather roads may be cut off for weeks or months at a time during rainy seasons, with the result that some villages and households may be relatively food secure during certain seasons of the year, and vulnerable or food insecure during other parts of the year. It is also important to note that periods of food insecurity do not track precisely with seasons. As assessments conducted in the months that followed Typhoon Ketsana in 2009 indicated, the more durable and widespread impacts of the typhoon were not experienced in the immediate aftermath of the storm, but four to six months after the event (WFP 2010).

The transition to commercial agriculture has also resulted in rural indebtedness (Kemp 2012). While the extent of this phenomenon is still not fully understood, it underscores the increasingly monetized rural context in which farmers make significant investment in agriculture inputs in order to meet export market demand for cash crops (Govt. of Lao 2013).

Physical Access

Improvements in market infrastructure, taken to mean not only the markets themselves, but also electrification, road networks, communications, and access to credit, have supported increased access to markets for both purchase and sale of food. Sixty-one per cent of Lao PDR has access to electricity (compared to 33 per cent in 2002), 84 per cent of the country is accessible via road throughout the year, and 42 per cent of all citizens own mobile phones (DOS 2009).

However, positive gains in infrastructure development are offset by increases in inflation, and rising household costs. As the Lao labour force is increasingly engaged in waged labour, there must be a trade-off in subsistence activities (agricultural activity for own production and consumption). Market purchases become increasingly important as a source of food supply (Govt. of Lao 2013). Rigg (2006) illustrates that households in

Lao PDR can be at once better off (improved incomes, access to markets, better services, electricity, etc.) and less food self-sufficient, producing less for their own consumption and becoming more reliant on market purchases.

Marked differences can also be seen between geographic, rural/urban, and/or ethnic affiliation in Lao PDR. Physical capital, human capital, and financial/social capital are often much higher in urban areas compared to rural, reflecting better access to infrastructure and services in urban areas. Natural capital, in particular productive land, rivers and access to forests, varies geographically across the country, with highly productive land suitable for rice production found in the lowland areas along major rivers, productive land not suitable for rice but appropriate for many cash crops found in the midlands/plateau areas, and less suitable land due to high degree of sloping found in the highlands (WFP 2008).

Also of importance in this context is access to Non Timber Forest Products (NTFPs). NTFPs are important as a source of dietary diversity in terms of both macro and micronutrients, but also as a source of household income, with NTFPs sold to purchase rice (Foppes et al 2011). Access to food therefore pertains not only to access to productive assets, but also to natural resources. With wild fish and animals constituting the single largest source of protein, access to lakes, rivers and forests is a vital component of household consumption and nutrition (WFP 2008). However, as a result of shifting patterns of agriculture, land tenure and access to land, food foraged and gathered from the wild has declined from 36.6 to 25.9 per cent (Foppes et al 2011). This underscores the point that even for rural agricultural households, growing food for self-consumption is only one of a series of methods for accessing food, alongside waged labour, sourcing NTFPs, market purchases, and bartering.

Social Access

Social access to food in Lao PDR is conditional on a number of inter-related geographic and cultural factors. The population of Lao PDR is ethnically quite diverse, with sub-populations organized into 49 groups across four linguistic categories: Lao-Tai, Hmong-Mien, Chino-Tibetan, and Mon-Khmer. The Lao-Tai populations, comprising 67 percent of the national total, tend to reside in agriculturally productive lowland areas around Vientiane and along the Mekong corridor. The Hmong-Mien and the Chino-Tibetan groups are generally found in the northern highlands and the Mon-Khmer can be found in both the Northern and Southern regions (WB 2010).

Ethnic groups that live at higher altitudes tend to have less access to food as a result of limited infrastructure and limited opportunities for settled agriculture. Ethnicity also bears important linguistic implications, such that populations who cannot speak the Lao language may be unable to participate in markets or take advantage of employment opportunities requiring languages other than their own. Proximity to regional opportunities is also important, because populations living along the borders with Thailand and Cambodia are able to take advantage of trade and employment opportunities in neighbouring states, whereas populations along the mountainous border with Viet Nam are less able to do so (MPI 2010).

Also of importance in terms of social access is the emergence of landless rural households. The 2012 Lao Agricultural Census (ACO 2012) records a threefold increase in the number of landless rural households over the past decade, amounting to 49,000, equivalent to six per cent of the overall population.

2.2.4 Thailand

With an average per capita GDP of US$3,893 Thailand has a much more robust economy than other countries in the region such as Cambodia, Lao PDR, Viet Nam and Myanmar with a far smaller segment of the population (8.5 per cent) living beneath the national poverty line (ADB, 2009c; World Bank, 2011). Impressive growth in Thailand has contributed to decreases in the number of people undernourished in the country falling from 30 per cent in 1990-1992 to 17 per cent in 2003-2005 (ESCAP, 2009). The drought-prone area of north-eastern Thailand, however, presents a challenge for national food security (ESCAP, 2009). In 2010 According to an FAO GIEWS report, a large area in the northern, central and eastern regions were affected by insufficient rainfall and rice crops were below normal (FAO, 2010).

As the world's largest exporter of rice, Thailand experienced a positive impact to its terms of trade in the face of rising food prices (Headey, 2010). However, such price rises have the result of increasing farm incomes while adversely affecting the poor in non-farming sectors (FAO, 2010).

Table 2.4: Food availability or supply of food commodity for Thailand population 2005 to 2010

Products	2005	2006	2007	2008	2009	2010
	000 MTs					
Cereals (excl. beer)	10535	10477	10107	10092	11482	13294
Starchy Roots	1480	1493	1466	1580	1432	1501
Sugar crops	307	375	347	377	426	438
Sugar and Sweeteners	2109	2413	2159	2223	1973	2317
Pulses	155	146	155	143	146	192
Tree nuts	19	13	31	35	33	36
Oil crops	1596	1432	1382	1161	1061	982
Vegetable Oils	523	432	506	523	519	500
Vegetables	2671	2398	2648	2664	2722	2772
Fruits	8911	9805	10762	9093	8670	8766
Stimulants	87	92	95	125	123	137
Spices	312	290	331	320	330	346
Alcoholic Beverages	2378	2945	3140	3051	2853	2369
Meat	1814	1897	2009	1851	1766	1841
Offals	47	64	56	59	63	74
Animal Fats	20	23	22	24	20	23
Milk (excluding Butter)	1969	1736	1600	1665	1514	1817
Eggs	599	634	631	651	712	753
Fish and sea food	2234	2236	2080	2080	2080	2080
Miscellaneous	16	12	22	23	26	34

Source: National Statistics Office and Office of Agricultural Economics, Thailand 2012

Cereals are the most consumed food items in Thailand followed by fruits. The food availability or supply of food commodity in terms of Kcal per person per day for Thailand's population from 2005 to 2010 is presented in table 2.5.Agricultural production in Thailand contracted by 0.6 per cent in 2009 due to price declines from the 2008 highs and pest infestations (ADB, 2010). Meanwhile, the country experienced sharp declines in manufactured and agricultural exports (ADB, 2010).

Table 2.5: Food availability or supply of food commodity (Kcal/person/day) for Thailand population 2005 to 2010

Products	2005	2006	2007	2008	2009	2010
Grant Total	2875	2886	2879	2828	2868	3116
Vegetable Prod.	2519	2546	2529	2498	2550	2784
Animal Prod.	339	340	350	331	318	332
Cereals (excl. beer)	1357	1369	1328	1355	1476	1623
Sugar and Sweeteners	309	351	312	319	279	328
Fruits	232	239	259	204	197	204
Vegetable oils	190	154	180	184	182	174
Meat	188	195	208	186	170	178
Alcoholic beverages	118	152	161	155	149	158
Oil crops	129	116	110	96	89	84
Starchy roots	61	62	62	68	59	60
Fish and sea food	61	59	59	58	58	57
Eggs	40	42	41	42	46	48
Spices	40	37	42	40	41	43
Vegetables	38	33	36	36	37	38
Milk (excluding butter)	40	34	32	25	35	38
Pulses	23	20	21	19	20	26
Tree nuts	4	3	7	8	7	7
Animal fats	7	8	7	8	7	7
Miscellaneous	3	2	5	5	6	8
Sugar crops	4	4	4	4	6	8
Stimulants	2	3	3	3	3	4
Offals	2	3	3	3	3	4

Source: National Statistics Office and Office of Agricultural Economics, Thailand 2012

It is expected that this trend will reverse as global demand and food prices rise again. Food insecurity in Thailand remains less acute in comparison with its Southeast Asian neighbours. The FAO (2010) noted that the food security situation in Thailand was " satisfactory" as of March 2010.The FAO stats for domestic consumption of various food items in Thailand from 2005 to 2009 are presented in table 2.6.

Table 2.6: Domestic Utilisation of food items in Thailand 2005 to 2009 (000 MT)

Product	**2005**	**2006**	**2007**	**2008**	**2009**
Cereals - Excluding Beer	15377	15023	15088	15731	16618
Starchy Roots	4621	3953	8290	12028	11394
Sugar crops	47107	45275	61147	69827	63476
Sugar & Sweeteners	2135	2445	2185	2250	1990
Pulses	186	159	168	156	159
Tree nuts	49	34	62	68	63
Oil crops	4067	3784	3851	3853	3561
Vegetable Oils	983	915	1109	1350	1629
Vegetables	3256	3116	3396	3272	3249
Fruits - Excluding Wine	7636	8262	9096	7619	7432
Stimulants	91	93	97	127	125
Spices	312	290	331	320	330
Alcoholic Beverages	2401	3038	3577	3385	3455
Meat	1830	1914	2027	1878	1788
Offals	47	54	56	59	63
Animal Fats	35	33	43	40	47
Eggs	739	776	776	797	858
Milk - Excluding Butter	1921	1652	1456	1578	1502
Fish, Seafood	3296	2746	2434	2103	2264
Aquatic Products, Other	29	109	5	146	112

Source: FAOSATAT 2013

There is significant increase in the domestic utilisation of cereals, starchy roots, sugar crops, vegetable oils, stimulants, alcoholic beverages, offals, animal fats, eggs and aquatic products from 2005 to 2009, while consumption of sugar and sweeteners, pulses, oil crops, milk, fish and seafood has been decreased since 2005.

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The MDER and ADER for the average Thailand population was respectively 1882 and 2404 kcal per day. Urban populations have on average marginally higher MDER and ADER than rural counterparts due to the higher population of adults in urban areas resulting from rural migration to cities to find work or to study. This was confirmed by the high MDER and ADER values for Bangkok and its three surrounding provinces. However, the Northeast region, which falls under the LMB region, had the lowest MDER and ADER than the rest of the regions.

Table 2.7: MDER, Average DER and DEC at various locations in Thailand

(kcal/person/day)

Location	Minimum Dietary Energy Requirement (MDER)	Average Dietary Energy Requirement (ADER)	Average Dietary Energy Consumption (DEC)
Bangkok and Surrounding Three Provinces	1918	2470	1940
Central	1885	2412	2090
North	1883	2408	2190
Northeast	1866	2375	2120
South	1878	2396	2040
Thailand Rural	1873	2387	2090
Thailand Urban	1900	2438	2080
Thailand	1,882	2404	2,090

Source: National Statistics Office and Office of Agricultural Economics, Thailand 2012

The average daily energy consumption of the Thai individual was 2090 kcal in 2011. This level of dietary consumption accords with the Recommended Dietary Allowances and Recommended Dietary Intakes for healthy Thais (Sirichakwal et al. 2011). DEC increases with rise in levels of income as more income increases access to food in terms of quantity and quality. Low income households had an average DEC of 1760 kcal/person/day which was below the average national MDER of 1882 kcal while the highest income households had an average daily DEC of 2450 kcal. The rural population had a slightly higher DEC than the urban population as the former are usually producers of food, which are available at lower prices. Differences in levels of DEC were noted among the five regions of Thailand. The North, which is home to a high proportion of the Thai rural population, had the highest DEC of 2190 kcal/person/day, while Bangkok and its three neighbouring provinces Nonthaburi, Pratum Thani and Samut Prakan had a low DEC of 1940 kcal.

2.2.5 Viet Nam

Viet Nam has experienced successful economic growth in recent years, transforming from one of the poorest countries in the world into a lower middle-income country by 2010. Viet Nam's poverty rate fell from 58 per cent in 1993 to 14.5 per cent in 2008 (World Bank 2012), and the country has reached five of the 10 original Millennium Development Goals. Viet Nam aims to continue its growth and reach middle-income status through the Socio-Economic Development Strategy (SEDS) 2011-2020.

Export restrictions imposed by Viet Nam are widely believed to have played a significant role in the surging of world rice prices during the 2007-2008 food crises (Headey, 2010). Viet Nam is the second largest exporter of rice and therefore such export restrictions can have a major impact on world markets. According to the ADB (2010) the agricultural sector (including forestry and fisheries) in Viet Nam grew in 2009 by a weaker than normal rate of 1.8 per cent, however increased external demand is expected to increase growth in agriculture and manufacturing in 2010 and 2011.

The food security situation in Viet Nam has improved dramatically over the past two decades. In 1990-1992 approximately 31 per cent of the population was undernourished, a figure that fell to 14 per cent by 2005 (ESCAP, 2009). GDP growth has averaged 7.1 per cent between 1990 and 2009 and per capita GDP has grown from US$631 in 2005 to US$1,032 in 2009 (ADB, 2009d; World Bank, 2011). Incoming FDI has also risen dramatically in recent years which ranged from US$1.3 billion to US$1.8 billion in the 2002-2006 period and reached US$9.3 billion in 2008. Despite this robust growth, 21.5 per cent of the population still lived on less than US$1.25/day in 2006 (ADB, 2009d).

Overall food security in Viet Nam has improved, both from domestic and imported sources. The Vietnamese consumption pattern changes, however, with a rising importance of fish, vegetable oils and fats and other food, beverage and tobacco products, at a cost of processed rice and vegetables and fruits. Trades in manufacturing and services continue to rise in prominence and display increasing trends over time. Despite the declining importance of the paddy rice sector in Viet Nam's economy, Viet Nam continues to be one of the main exporters of rice in the world, thereby contributing to global food security and notably that of Sub-Saharan Africa.

2.3 Poverty alleviation

2.3.1 Overview

Despite unprecedented economic growth in the Lower Mekong Basin countries over the past decade, the region remains one of the world’s poorest (MRC 2012). Currently the GDP/capita within the basin is amongst the lowest in the world with an average daily income of less than one US dollar per day. Still, the population continues to grow, with 80 million plus anticipated by 2025 (MRC 2004). More than 60 per cent of breadwinners in these countries hold occupations related to water. Therefore, rural poor, ethnic minorities, and disadvantaged women, are vulnerable to changes in water availability and accessibility (MRC 2012).

For the Mekong people, especially the poorest, water has always played an essential role in sustaining their livelihoods. Many are subsistence farmers reliant on rice, wetland plants and wild caught fish to provide them the protein they require. The fishery is of prime importance. For tens of millions of people, the water of the river system remains the primary source of nutrition. Unfortunately, the increasing population in the existing socio-economic environment is placing huge pressure on this fragile resource, particularly on the fishery, both directly through increased fishing and habitat loss, and indirectly through modification of water quality and quantity (MRC 2004).

In many places in the basin, fishery is one of the few sources of employment for an increasingly young, often landless rural population. Coupled with the pressures of population increase are the forces of nature. Flooding remains an important phenomenon for the sustainability of the wetlands and fisheries, however the incidences of flash flooding due to changes in land-use bring death, devastation and economic cost to the region. Plus the Mekong Delta needs to be protected against increasing saline intrusion (MRC 2004).

All countries in the region see agriculture as a vital part of their strategy for economic growth and poverty alleviation. The agriculture sector has been an important contributor to economic growth in Thailand and Viet Nam that has driven significant reductions in overall poverty in the last 15 years. GDP growth in agriculture has been demonstrated to benefit the poorest proportionately more (Ligon and Sadoulet 2007 in World Bank 2008). The greatest depth of poverty remains in remote rural areas, and absolute gaps between the richest and poorest quintiles are widening, which leaves rural areas lagging. Combating poverty effectively will require specifically pro-poor policies and programmes that look beyond economic growth to the overall development needs of the communities.

Osmani (2005) argues that agriculture was the key to Viet Nam’s success in reducing poverty in the period since 1990. While industry drove economic growth, generation of employment in the agriculture sector (aided by egalitarian land reforms) ensured that the benefits of growth were shared equitably. In contrast, Lundstrom and Ronnas (2006) concluded that stagnation of the agriculture sector was the major constraint to poverty reduction in Cambodia in the same period, with a fall in agricultural employment and productivity (exacerbated by concentration of landownership by the wealthy) resulting in highly inequitable and less sustainable growth. They conclude that for Cambodia to achieve sustainable economic development and poverty reduction "agriculture will have to resume its role as a main contributor to employment and income generation."

The people in Cambodia and Lao PDR are among the poorest in the world: their income is low, the availability of food is low, and they are suffering from important health problems, due to lack of hygiene and access to safe water and health facilities. Also in the North-eastern part of Thailand and the provinces of Viet Nam that are part of the basin, many people suffer from severe poverty. Poverty is closely related to access to cultivable land and appropriate amounts of water, as well as to fish (Kristensen 2001 p-317).

Throughout the basin, small farms are the main feature, many of which are close to or below subsistence level. Many farms produce a per capita income below US$100 per year. Farmers are forced to seek off-farm employment elsewhere. Many are at the mercy of rice traders and are caught in a poverty trap in which they are in debt to private money lenders to whom they have to sell their rice at harvest time at very low prices. Other farmers, for example those in the Delta outside the problematic saline or acidic areas, generate a significant rice surplus. This situation has led to a rather skewed pattern of income distribution (Kristensen 2001 p-317).

In overcoming persistent rural poverty, it is essential to address the regular and devastating effects of severe droughts and floods, which claim lives and property and cause substantial economic losses. All LMB countries have poverty reduction strategies that include water supply for drinking and irrigation, flood management, hydropower generation, fisheries and other uses of Mekong water.

2.3.2 Lao PDR

Lao PDR has grown rapidly since the inauguration of reforms two decades ago. During the 1990s, growth averaged 6 per cent per annum despite severe imbalances during the Asian crisis. Following successful stabilisation, growth continued to average close to 6 per cent during 2001-2004, accelerating in 2005-2007 to over 7 per cent. Inflation remained well below 10 per cent since 2005. Growth in Lao PDR has been pro-poor.

Based on the national poverty line, the poverty head count has fallen from almost half to one-third of the population during the decade ending in 2002-2003. The country's performance on other elements of poverty reduction, as summarised in the Millennium Development Goals, is mixed. Goals related to literacy, gender equality, child and maternal mortality rates, communicable diseases and safe water and sanitation are on track, although levels remain below low-income country averages. Goals for primary education, assisted births, and notably, child hunger, are unlikely to be met (Grawe 2010).

Without a doubt, the commitment to poverty reduction plays a central role in the Lao PDR's development strategies, and many international organisations are supporting these efforts. Knowledge about poverty is of the outmost importance for informed decision-making and for evidence-based formulation of policies. Not only should the current status of poverty in the country be understood, but also how it is defined and perceived by the peoples concerned, and how it changes over time. With rapid national and regional economic growth, there are concerns about the inclusiveness of current policies in terms of people and places (Epprecht et al. 2008).

Poverty in Lao PDR fell sharply since the early 1990s. Using a national poverty measure computed according to international standards, 1 in 3 persons (33 per cent) did not consume enough to meet basic needs in 2002/03. This compares to almost 1 in 2 persons (46 per cent) in 1992/93 and 2 in 5 persons (39 per cent) in 1997/98. The progress is remarkable. The share of poverty was reduced by 30 per cent in one decade, lifting one eighth of the total population out of poverty (PREMSU 2006)

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Table 2.7 summarises data on the share of poor individuals in percentage of total population across regions. Overall, it can be seen that the incidence of poverty has fallen since 1992/92, although the rate of progress slowed down during the second period. However, overall reduction in poverty during the second period hides substantial differences across provinces and regions. Poverty has continued to fall rapidly in many of the Northern provinces, which were clearly in the weakest position in 1997/98. By contrast, poverty has increased in some regions that were in a stronger position five years ago. The highest poverty increases are found in Vientiane municipality and some of the surrounding provinces. This pattern seems to confirm the hypothesis that the Asian crisis mainly hurt those parts of the country that were relatively well integrated with the Thai economy (Sida 2006).

Table 2.8: Total Poverty Headcount and Rural Poverty by Region in Lao PDR

	1992/93	1997/98	2002/03	Change 92/92 to 97/98	Change 97/98 to 02/03
Total Poverty	46.0%	39.1%	33.5%	-6.9%	-5.6%
Rural Poverty	51.8%	42.5%	37.6%	-9.3%	-4.8%
Vientiane Municipality	52.9%	11.1%	20.2%	-41.8%	9.0%
Northern Region	55.5%	48.6%	39.1%	-6.9%	-9.5%
Central Region	48.5%	41.5%	39.0%	-7.0%	-2.5%
Southern Region	51.9%	41.6%	41.6%	-10.2%	-6.1%

Source: Engvall 2006

Even though the population expanded by one million people between 1992/93 and 2002/03, the absolute number of poor declined from about 2.0 million to 1.8 million. Other welfare indicators confirm the improvement in living standards. First, food security has improved. Food poverty, based on a requirement of 2,100 calories per day and per person, fell faster than consumption poverty due to a steeper decline between 1997/98 to 2002/03 (PREMSU 2006).

2.3.3 Cambodia

During the last decade, Cambodia has achieved impressive economic growth with gross domestic products (GDP) averaging 10 per cent per annum during the 2004-2010 period. Besides its contributions to economic growth, agriculture sector contribute to social development, especially help reducing poverty for the people, mainly people who is living in the rural areas by creating rural employment of about nearly 70 per cent and contribute to poverty reduction as well (MAFF 2013). It is an important source of livelihood for 85 per cent of the population. Paddy production covers 84 per cent of cultivated land and contributes about 38 per cent of agricultural value added or 13 per cent of the national GDP in 2010. Paddy production has been crucial in creating employment and reducing the national poverty rate from 47 per cent in 1994 to 30 per cent in 2007 and 26.1 per cent in 2010 (MAFF 2013). The Royal Government of Cambodia (RGC) set the annual GDP growth target of 7 per cent and poverty reduction rate of 1 per cent per annum from 2009 onwards. Given its significant share in the national GDP, rice continues to play a crucial role in enhancing macro-economic stability, food security, and poverty reduction (ADB 2013a).

This growth momentum is expected to continue with projected growth rates of 6.7 per cent in 2013 and 7.0 per cent in 2014. It is driven by strong exports, private investment, agriculture, diversification, and a solid macroeconomic position. The rapid economic growth created employment opportunities which contributed to the decline in poverty headcount from 34.7 per cent in 2004 to 20 per cent in 2011. From 2004-09 Cambodia saw an even steeper decline in poverty rates. World Bank estimates suggest that Cambodia achieved the Millennium Development Goal (MDG) of halving poverty by 2009. During the field visits, the consultant team also identified other social and economic phenomena in rice growing villages associated with rapid economic growth. They include the increased importance of remittances from sons and daughters who went out to major cities in the household income, declining rural labour forces, aging of the remaining population, and expanding income gap between rich and poor. All the interviewed farmer groups claim the range of monthly remittances is about US$30 to US$40.

Despite the economic growth, Cambodia is one of the poorest countries in the region with poverty head count rates at around 32 per cent (World Bank 2009). The country is still struggling with a legacy of conflict and destruction that has left it weak and vulnerable on many fronts: social and physical infrastructure, health and education, governance and institutions, and knowledge and technology. Despite these critical shortcomings, the country has made tremendous progress over the last decade. The greatest achievement has been a return to political stability and a hugely improved law and order situation, enabling the country to reap rich peace dividends. In addition, the country has emerged out of the post-conflict reconstruction stage and has now entered into a new phase of economic development characterised by open economic policies, a focus on private-sector-led development and far-reaching macroeconomic reforms (Runsinarith 2011).

In Cambodia, the population living under the national poverty line of US$0.93 per capita per day in 2009 (Ministry of Planning, 2013) is defined as *the poor*. In 2011, about 20.5 per cent of Cambodians live below the national poverty line indicating that at least one in five Cambodians are still living in deprivation (World Bank 2013b). They lack sufficient resources to meet their daily needs. More than 80 per cent of the Cambodian population is rural and mainly employed in the agricultural sector. Many small-scale farmers practice agriculture at subsistence level, using traditional methods that are low in productivity (ADB 2009f). According to a report of IFAD on rural poverty in Cambodia, Cambodia's poor people number almost 4.8 million and 90 per cent of them are in rural areas. Most of them depend on agriculture for their livelihood, but at least 12 per cent of poor people are landless. The report also identified that small-scale farmers practice agriculture at the subsistence level, using traditional methods. Productivity is low. Two thirds of the country's 1.6 million rural households face seasonal food shortages each year. Rice alone accounts for as much as 30 per cent of household expenditures. Rural people are constantly looking for work or other income generating activities, which are mainly temporary and poorly paid.

The rural citizens are the people who have the least access to education, health and other public services because of poor infrastructures and lack of government investment in areas where it matters most. In 2007, education expenditure only accounted for 1.6 per cent of Cambodia's total GDP putting it amongst the ranks of other poorer nations (CIA 2011). As a result, only 78 per cent of adults above the age of 15 are literate (World Bank 2013b). According to the IFAD rural poverty report the country's poor people include subsistence farmers, members of poor fishing communities, landless people and rural youth, as well as internally displaced persons and mine victims. Tribal peoples and women are generally the most disadvantaged.

According to ADB (2013b) the northwest region is one of the poorest and most isolated areas in Cambodia. Due to war and civil strife it has been left out of many development efforts during the past decades. Consequently, it suffers from inadequate investments in infrastructure, services, and institutional capacity building. Agriculture is the predominant economic activity and the major crop grown is rice, the staple food. Agricultural productivity is low and most rural areas in the northwest are exposed to food deficit (in some areas up to 6 months a year) even though Cambodia is, in average to good years, considered self-sufficient in rice. Lack of water control and management and low levels of agriculture technology constrain yields. Overall availability of water in northwest Cambodia is limited and resources need to be managed prudently. There is, however, a significant potential to raise agricultural production and rural incomes, and consequently reduce poverty in areas, where an enhanced supply of water is managed properly and where irrigated agriculture is protected from flooding.

2.3.4 Thailand

Thailand is a middle-income country and is considered as a newly industrialised country, with tourism and exports contributing significant shares of income to the economy. Almost all of Thailand's poor people reside in rural areas and most are directly involved in agricultural production (Warr 2004). Although the agricultural sector has declined its importance in terms of its share in economic growth, the majority of the population is still engaged in farming activities. The number of employed persons found in the agriculture sector is significant (almost 40 per cent of the labour force) (Thuvachote 2011).

Thailand is on track to achieve most of the Millennium Development Goals by 2015. Primarily due to the high rates of economic growth, poverty has been falling steadily since the late 1980s. Over the last decade, poverty has been reduced from its recent peak of 42.6 per cent in 2000 (a result of the 1997 crisis) to about 13.2 per cent in 2011, and the proportion of underweight children fell by half between 1993 and 2006. Thailand continues to make progress towards meeting the Millennium Development Goals (MDGs) and is likely to meet most of the MDGs on an aggregate basis. The maternal mortality and under-five mortality rates have been greatly reduced and more than 97 per cent of the population, both in the urban and rural areas, now have access to clean water and sanitation. Nevertheless, there continues to be spatial variations with some regions and ethnic groups lagging behind, and there are some concerns about the environmental sustainability goal (WB 2013).

However, benefits of Thailand's economic success have not been shared equally, with some regions—particularly, the North and Northeast—lagging behind the rest of the country in terms of poverty reduction. Inequalities in terms of incomes and opportunities have been persistent. The Gini coefficient, a measurement of income inequality in Thailand, has been persistent at around 0.45 for the last two decades. Much of the inequalities are inter-regional with the North and the Northeast lagging behind other regions of the country (WB 2013). Poverty in Thailand, as measured by the proportion of the population with incomes below the national poverty line, declined steadily during 2000-2009. Table 2.9 shows that the number and per cent of poor people in the whole kingdom decreased from 12.6 million (20.98 per cent of the total population of 59.9 million) in 2000 to 5.3 million (8.12 per cent of 65.0 million) in 2009.

Table 2.9: Poverty line, number and percent of poor people during 2000-2009

	2000	2002	2004	2006	2009
Poverty line (baht/month)	1,135	1,190	1,242	1,386	1,586
Percent of poor people	20.98	14.93	11.16	9.55	8.12
Number of poor people(million)	12.6	9.1	7.0	6.1	5.3
Population (million)	59.9	61.2	62.9	63.4	65.0

Source: Office of National Economic and Social Development Board.

Table 2.10: Percentage of poor people by region, during 2000-2009

Location	2000	2002	2004	2006	2009
Bangkok	1.71	2.24	0.78	0.51	0.86
Central	9.03	7.63	4.47	3.31	2.54

North	23.10	20.29	15.68	12.00	11.08
Northeast	35.34	23.06	18.58	16.77	13.67
South	16.64	9.56	6.03	5.49	4.72
Whole Kingdom	20.98	14.93	11.16	9.55	8.10

Source: Office of National Economic and Social Development Board

Across region, table 2.10 shows the highest percentage of poor can be found in the Northeast region (13.6% of the population below the poverty line) followed by the North (11.1%), the South (4.7%), the Central (2.5%) and Bangkok (0.8%).

2.3.5 Viet Nam

Despite the country's growth, Viet Nam's rural populations continue to face challenges in overcoming poverty. Many rural farmers are landless or have access only to small plots of low-quality land, and opportunities for off-farm employment continue to be scarce. Rural villages, particularly in the country's upland and coastal areas, face frequent natural disasters and are vulnerable to negative seasonal weather patterns (IFAD 2012). The Northern midlands and mountain areas are the poorest region, followed by the Central Highlands and the North Central and Central Coastal areas. The lowest poverty rate was seen in the South East (VHLSS 2010).

The poverty rate for the whole country in 2010 decreased to 10.7 per cent according to poverty lines issued by the Government for the period 2006-2010 (200 thousand VND/person/month for rural areas and 260 thousand VND/person/month for urban areas), it was 13.4 per cent in 2008, 15.5 per cent in2006 and 18.1 per cent in 2004. By new poverty lines of the Government for the period 2011-2015 (400 thousand VND/person/month for rural areas and 500 thousand VND/person/month for urban areas), the national poverty rate in 2010 was 14.2 per cent, it was 6.9 per cent in urban areas and 17.4 per cent in rural areas (VHLSS 2010). Percentage of poor in the whole country and in the 6 regions is presented in table 2.11.

Table 2.11: Percentage of poor by region during 2004-2010

	2004	2006	2008	2010	2010*
Whole Country	18.1	15.5	13.4	10.7	14.2
Urban	8.6	7.7	6.7	5.1	6.9
Rural	21.2	18.0	16.1	13.2	17.4
Poverty in Different Regions					
Red River Delta	12.7	10.0	8.6	6.4	8.3
Midland and Mountain Areas	29.4	27.5	25.1	22.5	29.4
North Central and Central Coastal Areas	25.3	22.2	19.2	16.0	20.4
Central Highlands	29.2	24.0	21.0	17.1	22.2
South East	4.6	3.1	2.5	1.3	2.3
Mekong River Delta	15.3	13.0	11.4	8.9	12.6

Source: VHLSS 2010

* Poverty rate in 2010* is estimated by the Government's poverty lines for period 2011-2015

According to IFAD (2012) some 75 per cent of Viet Nam's population lives in rural areas, accounting for more than 90 per cent of the poor. Agriculture provides 60 per cent of all employment. The majority of the rural population makes a living from growing crops (rice accounts for 45 per cent of agricultural production), fish-and livestock-raising, and collecting forest products although land and water degradation seriously threaten the sector. In 2008, 11.2 million (18.7 per cent) of the country's 60 million rural inhabitants still lived below the poverty line.

Progress in reducing poverty has been uneven, especially in terms of the gap between regions and ethnic groups. The Gini coefficient was 37.8 in 2007. The income share of the highest 10 per cent was 29.8 in 2006 while that of the lowest 10 per cent was 3.1 per cent. Poverty remains much higher among ethnic minorities than among the Kinh majority, and there is slower progress in poorer regions with high concentrations of ethnic minorities (IFAD 2012).

2.4 Climate change

Current climate change estimates that major environmental changes are likely to occur due to climate change practically in every part of the world, with majority of these changes being felt through modification of hydrological cycle, for example floods, droughts and storms. Climate change impacts are also estimated to be particularly severe in many developing countries. It is therefore no surprise that climate change adaptation has become one of the focal points of current development discussion. The negative impacts of climate change are likely to bring new challenges as well as to magnify already existing ones, particularly when looking things at more long term. Climate change includes long-term changes e.g. in mean temperature and precipitation, but also potential increases in the frequency of extreme climate conditions that can occur in much more short-term.

The Mekong River Basin is currently undergoing rapid social, economic and political changes that have wide-reaching ecological and social consequences (Varis et al. 2008). Within the past few years, climate change has emerged as one potential additional driver, particularly in terms of more long-term changes. Climate change in the Lower Mekong Basin is expected to result in an increase in the frequency and severity of droughts, floods and saltwater intrusion. Such changes are expected to affect natural ecosystems, agriculture and food production, and also exacerbate the problems associated with supplying the region's increased demand for food. The impacts of such changes are likely to be particularly severe on Lower Mekong Basin communities, given their strong reliance on natural resources for their livelihoods. Most of the climate change studies undertaken in the GMS have attempted to quantify the impact of global warming on the regional climate by comparing mean annual temperature and rainfall averaged over successive periods whose length generally varies from 10 to 30 years. For instance, Mac Sweeney et al. (2008) detected possible change in rainfall and temperature time series in South-East Asia by comparing averages from a base line period (1970-1999) with mean values for the 2030s, 2060s and 2090s. Ruosteenoja et al. (2003) calculated changes in seasonal surface air temperature and precipitation in

SE Asia between a baseline period (1961-90) and three 30-year periods centred on the 2020s, 2050s and 2080s. Projections resulting from these studies are compared in Table 2.12.

Table 2.12: Comparison of projected climate changes from different studies

Authors	Snidvongs et al. (2003)	Hoanh et al. (2003)	Ruosteenoja et al. (2003)	TKK and SEASTART (2008)	Eastham et al. (2008)	Mac Sweeney et al. (2008a, b,c)	ADB (2009a)	Lacombe (2009)
Location	Lower Mekong catchment	Mekong Basin	SE Asia	Lower Mekong catchment	Lower Mekong catchment	Cambodia, Viet Nam	Thailand, Viet Nam	Greater Mekong Subregion
Models	CCAM	HADCM3	7 GCMs	ECHAM4-PRECIS	11 GCMs	15 GCMs	MAGICC (GCM)	PRECIS/ECHAM4
Scenarios	Not specific	A2, B2	A1F1, A2, B1, B2	A2	A1B	A2, A1B, B1	A1F1, B2	A2, B2
Period	From [1×CO2] to [2×CO2]	1960-2099	1961-2095	1960-2099	1976-2030	1970-2090	1990-2100	1960-2049
Projected changes in annual rainfall	Not explicitly quantified	-1.64 mm/yr. to +4.36 mm/yr.	Either >0 or <0, depends on models and scenarios. Almost always insignificant	Increase (not explicitly quantified)	+0.1mm/year to 9.9mm/year	+0.3 mm/yr. to +0.6 mm/yr.	1990-2050: +1.26 mm/yr. to -1.62 mm/yr. (B2); 0.66 mm/y to -1.14 mm/yr. (A1F1) 1990-2100: +3.27 mm/yr. to +4.91 mm/yr. (A1F1) and - 1.63 mm/yr to -2.45 mm/yr. (B2)	No significant change at the whole GMS scale
Changes in seasonal	Dry season drier and		Dry season drier and	Dry season drier and	Wetter wet season (+1.7	Wetter wet season : +0.8 to +1.5 mm/yr.		Wetter wet season in North Myanmar

rainfall pattern	longer Wet season delayed by 1 month		longer Wet season delayed by 1 month	longer Wet season delayed by 1 month	to +6.1 mm/yr.) Drier dry season (-0.3 mm/yr. not significant)	(KH); +0.4 to +1.5 mm/yr. (VN) Drier dry season: -0.7 to -0.1 mm/yr. (KH); - 0.3 to - 0.1 mm/yr. (VN)		and Gulf of Thailand (from +0.2 to +0.6 mm/yr.) Drier dry season on both sides of Gulf of Thailand (- 2.5 to -2.8 mm/yr.)
Temperature	+ 1° C to +3° C (over a 100-yr. period)	+0.026 C /yr. to +0.036 ° C/yr.	+0.026 C /yr. to +0.036 °C /yr.	Increase (not explicitly quantified)	+0.012 °C/ to +0.014 °C/ yr.	0.00 °C /yr. to +0.06 °C /yr.	+0.03 °C/yr. to +0.06 °C/yr.	+0.023 °C/ yr. to +0.024 °C/yr.

2.4.1 Impacts on Agriculture

Alteration of climate in the LMB will bring about changes in temperatures, rainfall, and hydrological conditions that will affect agricultural production. Climate change may induce geographical shifts in the suitability of the basin for several crop species including potentially:

- Suitability of industrial crops like rubber, robusta coffee and cassava shifting to areas of higher altitude with optimal suitability in 2050 centred on northern Thailand, northern Lao PDR and central highlands;
- Plains and lower altitude areas becoming less suitable for rubber, robusta coffee and cassava, especially in eastern Cambodia;
- Dramatic increases in precipitation in central Lao PDR affecting cassava, soya and maize culture. For these crops, the rainfall suitability also decreases in central highlands and eastern Cambodia;
- An increase of suitability is projected in Thailand due to an increase of rainfall during the crop;
- Maize yield projections show a general decreases across the basin, with Gia Lia (-12%), Mondulkiri (-6%), Kampong Thom (-6%) provinces being the most severely affected.
- Climate change will have less effect on lowland rain-fed rice than other crops; however it is vulnerable to increased temperature in the wet season, decreased water availability in the dry season, and salinity intrusion in the delta.

Impacts of Climate Change on Yield

Climate change may have great impacts on the yield of the crops in the LMB in a number of ways such as increase in temperature and precipitation; prolong droughts and floods etc. The effects of climate parameters on crop yields are discussed in the following subsections.

a. Change in Temperature

A basin wide temperature increase of 0.79˚C with greater increases for colder catchments in the north of the basin (ranges from 0.68 to 0.81˚C) by 2030 is projected, which may lead to a decline in the crop yields. Increased temperature can reduce yields of crops and pastures by preventing pollination, and through dehydration. The yield of rice decreases by 10 per cent for every 1 °C increase in the minimum temperature during growing season (Peng et al. 2004). Similar impacts have been reported for other crops including wheat (Cruz et al. 2007). High temperatures at flowering of rice can induce floret sterility and can limit grain yield (Matsui and Osama 2002), which can be offset by promoting the adoption of high temperature-tolerant cultivars. Higher temperatures and longer growing seasons could result in increased pest populations (FAO 2003). Changes in temperature could affect ecology, and warmer winters may result in decreased winter mortality of insect populations. Increases in temperature may speed up growth rates or crop pathogens and so increase reproductive generations per crop cycle, making the crop more vulnerable. Increased CO_2 levels could enhance the competitiveness of C3weed species (Ziska 2003).

Higher temperatures will increase evapotranspiration, thus increasing the water demand of crops and pastures in both rain-fed and irrigated systems. Irrigation demand in semiarid regions of Asia is estimated to increase by at least 10 per cent for each 1 °C rise in temperature (Fischer et al. 2002). Increased water use by crops and pastures will impact on the availability of water for environment and other uses. Changes in temperature and rainfall patterns could change the viability of particular crop types or varieties, requiring new varieties or a shift in the cropping pattern.

b. Change in Precipitation

Annual precipitation is also projected to increase by between 3–14 per cent (35 – 365mm) throughout the basin. The largest increases in precipitation will occur in the historically wet areas of the central and northern Annamites and east to the floodplain between Vientiane and Pakse where increases of up to 18 per cent or 365mm are expected to occur. The northern mid-elevation areas of Laos PDR and Thailand may also experience a large increase in precipitation (Mekong ARCC 2013).

Lower increases in annual precipitation may occur in the Khorat Plateau, Cambodian floodplains and the Mekong Delta. In these lowland areas annual precipitation will increase by between 3 to 10 per cent. These areas are historically drier so this translates to an increase of only 50 to 100 mm. The ecozones associated with these areas may experience significantly less changes in rainfall than the ecozones to the north and east. The Vietnamese highlands will also see a low percentage increase in precipitation of between 5 to 8 per cent (an increase of 175mm in absolute terms) (Mekong ARCC 2013).

Rain fed agriculture is the main farming system in the LMB; with rain fed rice the dominant crop, representing 75 per cent of agricultural area. The Cambodian floodplain supports a diverse rice based farming system, where the different cropping patterns for rice depend on flood duration and receding water. The Mekong Delta is the most intensive rice growing region in the LMB, with triple rice cropping in the fresh water areas. Yield modelling for rice and maize indicates a decrease in yield by 2050 (Mekong ARCC 2013) mainly due to higher day time temperatures during the crop season (Welch et al. 2010).The combined effect of increased temperature and excessive rainfall could induce a significant yield drop in soybean, maize and cassava crops.

c. Droughts

The period of agricultural drought per year may significantly increase in large areas in the south and east of the basin by 2050. An agricultural definition of drought is “drought month occurs when the precipitation in that month is less than 50% of the potential evapotranspiration”. Using this definition the Cambodian floodplain, Vietnamese highlands, southern Lao PDR and areas of the delta will experience a 10–100 per cent increase in drought months— an increase of around one drought month per year. In the north of the basin in areas such as Chiang Rai and northern Lao PDR, there will be a decrease in drought months of up to 25 per cent— a decrease of around two weeks of drought per year (Mekong ARCC 2013).

The principal costs of drought in the LMB relate to the impact of agricultural drought: reduced yields or total loss of crops, especially rice, together with reduced livestock and fishery yields. The period of agricultural drought per year may significantly increase in large areas in the south and east of the basin by 2050. The Cambodian floodplain, Vietnamese highlands, southern Lao PDR and areas of the Delta will experience a 10–100 per cent increase in drought months— an increase of around one drought month per year. In the north of the basin in areas such as Chiang Rai and northern Lao PDR, there will be a decrease in drought months of up to 25 per cent— a decrease of around two weeks of drought per year. Prolonged droughts will cause a significant reduction in yields of all crops, particularly in rain fed rice yield which is mainly dependent on rain water (Mekong ARCC 2013).

d. Floods

The higher incidence of extreme events such as storms and heavy rainfall will increase the vulnerability of the most farming ecosystems in the region. An increase in flooding in all parts of the basin, with the greatest impact in downstream catchments on the mainstream of the Mekong River is expected by 2030 (MRC 2010a). The lowlands will experience higher incidence of floods and flash floods.

Extreme floods, such as the one in Viet Nam in 1999 and in Cambodia in 2000, destroy fields planted with crops. Relief efforts were partly in vain, due to the poor quality of commercial seeds for replanting. The standing crops in 20 per cent of Cambodia's rice paddy fields (400,000 hectares) were washed away in 2000. Furthermore, the flooding led to destruction of agricultural land, thereby affecting agricultural productivity. Floods also have an adverse impact on the countries' efforts to build up its human resources.

Sea level rise and increasing average and extreme flood volumes will increase the depth and duration of floods in the Vietnamese Delta and Cambodian floodplains. Large areas of the delta which were historically rarely or never flooded to depths of 1.0m and 0.5m are projected to be regularly inundated to these levels. Maximum flood depths are projected to increase by over 1.0m with the highest increases along the East Sea coastline. Relatively minor increases in flood depth and duration are projected for the Cambodian floodplains (Mekong ARCC 2013).

2.4.2 Impacts on Fisheries

Freshwater capture fisheries contribute significantly to the income and nutrition of the poorest groups in the LMB. They are the primary source of animal protein for populations within the basin and in countries like Cambodia, contribute 65 to 75 per cent of total protein in the diet (Ringler and Cai, 2006).

- Climate change may affect the composition and abundance of fish species through changes to fertility, recruitment, nutrition and growth patterns.
- Direct impacts on the wild fish population will occur over a longer term through the effects of temperature on metabolism, growth, and distribution of aquatic organisms, and the effects on the food web through changes in the lower trophic-level production or in the abundance of higher-level predators.
- Exploitable biomass in fisheries is more sensitive to dry than flood-season conditions (Halls et al. 2001); so fisheries are very vulnerable to decline in dry season flows.
- Indirect impacts include changes of the aquatic regime and habitats due to sea-level rise and saline intrusion, eutrophication of coastal waters and lakes with effects on wild fish and cage culture (Thanh et al. 2004), and acidification impacting calcification and shell formation of molluscs.
- Increased frequency and severity of coastal events such as storm surges can cause loss of stock, and a large number of escapees from aquaculture of exotic species can impact on natural populations and biodiversity (Na-Nakorn et al. 2004).
- Rise in water temperature tends to increase the spread of disease organisms, affecting wild and cultured fish.
- Black fish, which have limited migrations, appear more 'climate-proof' than migratory fish and upland fish and may be expected to increase in the proportion of fish catches as temperatures increase; and
- Aquaculture could be more vulnerable to climate change than capture fisheries, with flash floods causing a sudden drop in salinity and inviting disease of coastal shrimp ponds in Viet Nam.

- Impacts of climate change on the production of wild fish could potentially affect supply of fishmeal and fish oils, which are key diet components for aquaculture.

2.4.3 Impacts on Livestock

Livestock such as cattle, buffalo, poultry, and pigs are important sources of food and cash income in poor communities. Buffalo and cows in particular also provide a savings "safety net," as key household assets in lean economic times. However, livestock are vulnerable to changes in temperature and extreme weather events, which can increase mortality and make survivors more susceptible to diseases.

- Higher temperatures will have little measurable impact on individual animals in low intensity systems but multiplied across villages to regions the impacts may be significant.
- With higher temperatures the water demand for pastures will increase. Livestock water demand per head will also increase with increasing temperatures.
- Changes in rainfall will affect livestock units through feed and animal health issues. (Changes in the availability, quality and price of feeds are fundamental to all livestock production systems, as feed costs typically account for between 65 and 80 per cent of production costs).
- Pathogens will likely be affected in terms of viability outside hosts and rates of proliferation by humidity levels and the quality and quantity of vector breeding sites. Wetter periods increase the likelihood of disease transmission through fomites, increasing the importance of employing effective bio-security measures.
- Wild species in the LMB—which are important genetic resources—will be threatened by climate change directly and indirectly through loss of habitat, hunting and the threat of infectious diseases.

2.4.4 Impacts on Ecosystem

The diverse and interlinked role natural systems play in providing 'natural' resilience to climate change will become increasingly important as the effects of climate change intensify over time. The highland and lowland forests and riparian areas, flooded forests and floodplain grasslands, peat swamps, mangroves, coastal and estuarine systems, host many important species of global significance and provide services that contribute to linked agriculture, fisheries and livestock farming systems.

- There will be about 1 ^{o}C decrease for every 100m of elevation in tropical to subtropical areas. While there will be considerable time lags, some vertical shift in ecosystems can be expected as temperatures rise.
- Global projections are that the incidence of extreme climate events is likely to increase (IPCC, 2007). Wassmann et al. (2004) projected that a sea level rise of 20-45 cm will seriously aggravate flooding, with impacts in all three rice cropping seasons. Dasgupta et al. (2007) projected that a sea-level rise of 1 m would affect more than 5% of Viet Nam's land area (mainly in the deltas of the Red and Mekong). These projections do not take account of storm surge or the impact of salinity intrusion.
- Accelerating loss of populations and species due to extreme temperatures, coupled with drying, which is a significant driver of biodiversity loss;
- Reorganisation of plant and animal communities and new 'problem' species entering communities;
- Sea-level rise and saline intrusion will reduce viable crop areas in the deltas and coastal areas. Saline intrusion already affects 1.4 M ha in the Mekong Delta; further rises in the sea level will require extension and enhancement of existing infrastructure to protect crop areas.

2.5 Relevant organisations and programmes

2.5.1 Regional level

During the consultation with the experts at the Regional Offices such as FAO/RAPA in Bangkok, ADB/ASEAN Regional office in Bangkok, UNESCAP, UNDP and MRC Programme offices in Phnom Penh and Vientiane, several initiatives in relation to crop projection in the context of food security and poverty alleviation were highlighted. Their main features are provided below.

(1) The ongoing FAO study has assessed the sensitivity of carbon emission on global warming, the impact on food security less drastic than projected earlier.
(2) The Development Planning Section of the UNESCAP under its UN Regional Coordination Mechanism, has formed a Working Group on Poverty and Hunger Reduction headed by FAO. This WG is preparing a regional road map. The road map has emphasised improvement in agricultural productivity linking with poverty with an aim of access to food. The key issues addressed the importance of linking agriculture with other sectors by looking at the food price policy affecting the poor amongst others.
(3) FAO/RAPA emphasises regional collaboration in planning food security and poverty reduction, which also includes natural resources management issues. The RAPA also encourages the policies which are integrated in defining approaches by providing policy interaction fora amongst the Member Countries. The third area of collaboration amongst LMB countries is developing Land Cover Classification system by specifying Agro-ecological Zones (AEZs). Thailand has already made such AEZs based development plan for integrated plant nutrition management, conservation agriculture disaster management. FAO RAPA is assisting LAO PDR and Cambodia to introduce such systems in place.
(4) ADB is helping the GMS countries to develop GMS Drought Monitoring System through use of real time data. Also Manila office is assisting collaboration amongst GMS countries to develop GIS based Agriculture Information System. With assistance from ADB, ASEAN is developing a plan on ASEAN Integrated Food Security.

2.5.2 Country level

a. Cambodia

The current strategies of the Government of Cambodia to address the issue of food security centre around improvement in production, farmers' income and improved nutrition status of the poor. For achieving this, the government has placed emphasis on allocating additional resources in the NW area through its special rural development programme, supporting small holders, fishers and farmers around the Tonle Sap lake, commercialisation and promotion of modern technology and improved varieties of crops in the productive low land area by connecting farmers to the market.

In order to effectively implement these strategies, the government has outlined its support activities at national, provincial and local level. At the central level emphasis are placed in the eradication of hunger and malnutrition, provision of goods and services in order to reduce poverty including social protection and more inclusive development, and increasing resilient livelihood. The government is implementing an administrative management reform process at the provincial level; and at the local level, village groups will be involved in drafting and implementing their own priority plans.

The research and training components are coordinated amongst the Cambodian Agriculture Research and Development Institute (CARDI) and the Royal Agriculture University (RUA). While the improved varieties of crops and breeds of animals are tested and developed by CARDI, the required trained manpower is supplied by RUA. RUA faculty is also involved in providing training and participating in transfer of technology to the farmers at the provincial and district levels. The Statistics Division within the Ministry of Agriculture, on the other hand, collaborates on collecting and depositing provincial and district level information on staple crop areas and production figures; major cash crop areas and production figures; and, livestock statistics including fishery statistics. The Statistics Division has recently collaborated with the FAO Country office to conduct the first Agriculture Census for the country.

The Department of Agricultural Extension (DOAE) oversees the recruitment and placement of agricultural technicians both at the provincial and district level in one hand, it also empowers the farmers through development of farmers organisations and agricultural cooperatives to make the farmers part of the value chain system on the other. The prime target of DOAE thus is the Commune level to increase crop yield, cropping intensity, diversification and training of farmers to form business enterprises. These are achieved through organisation of field days, plot demonstration and enterprise development trainings. Four important AEZs are focused in emphasising development focus which include: Mountain and Upland Zone, Tonle Sap Zone, Flat Plain Zone and Coastal Areas.

Provincial and Local Level Programmes: The consulting team visited Battambang and Kampong Chan Province Offices. Four important collaborative projects for capacity building in enhanced food security are in place in the province. The Agriculture Productivity Enhancement Project, supported by JICA, targets nine districts working through the Agriculture Development Community (A.D.C). It places its importance on quality seed use and dissemination. The second project is supported by the EU and it aims to initiate a close working relationship between Agriculture Extension Agents and local authorities. The EU has supported farmers improvement in seed production and Integrated Pest Management (IPM) through Farmers Field Schools and Farmer-to-Farmer Trainings. UNDP has also supported a project on Climate Change and Adaptive Livelihood Agriculture Community (CALA) in order to protect farmers from natural disasters. The project also links farmers to the market through agricultural cooperatives.

The provincial staffs suggest the following in order to achieve food security and reduce poverty: emphasis on crop diversification, focus on agricultural mechanisation by small farmers, emphasis on raising livestock in upland area as a risk reduction activity, improved nutrition content in animal feed, and promotion of home gardens with local green houses.

b. Lao PDR

The National Food Security Strategy 2001-2010 of Lao PDR has emphasised four components namely, food availability, food sustainability, food accessibility and food safety. Also the government has approved a decree to achieve food availability, food sustainability, food accessibility and food safety. To achieve food availability, emphasis is placed on rice growing along the Mekong where plenty of water is available for multiple cropping in a year. For achieving food sustainability, alternative cropping plans and technology including ground water extraction have been emphasised for nearly 50,000ha of farm area affected by flood and drought. For food accessibility, special remote-area development programmes are implemented to improve infrastructure which promote cash crops by linking local community to markets. The government has also outlined the importance of food safety both by improved storage and nutrition awareness programmes. The current policy implemented in Lao PDR since 2012, targets potential areas for further improvement. For example, in the lowland rice producing provinces in Khammouane and Savannakhet, the government has emphasised increased productivity of rice both by increasing cropping intensity and technology improvement. There is a special programme for ethnic minorities in the northern areas of Lao PDR to intensify farming via irrigation development and a package of improved farming techniques in addition to infrastructure development. The 2016-2020 planning document has again put its emphasis on food security, commercial crop and livestock production placing emphasis on value chain and protection and production of forest for improved livelihood.

Provincial, District and Local Level Programmes: The consulting team visited three provincial offices in Vientiane, Khammuane and Savannakhet. In Vientiane Province they visited the Tulacom District Agriculture Development Office. The District Agriculture Office appoints an agricultural focal point based on the recommendation of the local level commune. The focal point reports the seasonal progress of activities, their respective planting area for major crops, varieties and associated problems if any. Three major crops were grown in this district: sweet corn (940ha), corn for animal feed (715ha) and rice (9,150ha). There are two sources of knowledge for agricultural extension. One comes from involvement in the outside project activities and collaborative trainings organised; and the other source of knowledge comes from government research set up e.g.; demonstration plots in the farmers' fields and new released varieties adaptation trials conducted by national research centres.

The Khammouane PAFO has placed its importance on three major crops namely, rice, cassava and maize. The central government chose Khammouane Province as a pilot province to implement their new policy to export rice. On their visit to the Nangbok District Agriculture Office of Khammouane Province, the team was briefed about the Netherlands Development Organisation's (SNV) project on Smallholder Development

Programme (SHDP) benefiting 41,000 farmers from 7,000 households. The project area covered 11,100ha of wet land rice, 1,800ha of dry land rice and 800ha of other crops. The SHDP had focused on improvement of 25 existing irrigation systems by transferring improved techniques of irrigated farming and improvement in the quality of rice for better market value. The project had generated a GDP of USD 1200/person/year and it covered 95% of the farmers in the project area. The second project implemented in the district was by World Bank assisted Khammouane Development Project focused on irrigation rehabilitation and new development; and the third one was SHDP funded by ADB on a project related to improving production of commercial agricultural enterprises.

The PAFO of Savannakhet Province has promoted 11 major crops in the province. Rice is one of the major crops that the government has a target to expand the planting area of dry season rice from 30,000 ha to 50,000 ha by 2020. Due to the presence of international highway number 9, the province faces major food security issues both in terms of opportunities and challenges to agricultural development, especially when Lao PDR opens up for free trade after the opening of the ASEAN Economic Community (AEC) in 2015. The challenges will be a highly competitive market, unpreparedness of Lao PDR compared to neighbouring countries, anticipated increase in cost of production and higher risk associated with market uncertainties. Therefore, the immediate strategies should include focusing on organic farming, a policy to allow farmers to use subsidised electric tariffs for pumping and other associated farming operations, introducing water use efficiency; focusing on crops which have good value chain, and improving processing and packaging. Out of 15 districts, 4 are located in hilly areas which need continuation of special government projects such as poverty reduction fund for improving infrastructure development and skill development training, continuation of rural development projects implemented by (I) NGOs and Nutrition improvement programmes.

c. Thailand

The Thai government has focused on development of larger irrigation projects and developed several improved varieties of area specific crops in the Provincial Offices of Agricultural Research and Development (OARD). In the interaction with TNMC line agency officials, it was emphasised that several aspects of food security and poverty alleviation could be achieved through regional collaboration and Thailand is willing to share its ongoing experiences such as SMART farmer concept, GAP and Q-process as well as scheduling computerised irrigation control in large irrigation projects. The major policies related to agriculture production being implemented in Khon Kaen Province and other parts in Northeast Thailand include 1) promotion of youth farmer groups, 2) promotion of smart farming, 3) reduction of chemical use and production cost, 4) promotion of Good Agricultural Practices (GAP), 4) research on climate change adaptation at farm level and, 5) land use zoning.

Provincial, District and Local Level Programmes: At the provincial level, such as in Khon Kaen, Yasothon, Kalasin and Ubon within the LMB region, the consulting team was briefed about several agricultural and rural development-related programmes, which were implemented to alleviate poverty; i.e. technology transfer programmes targeting the poor, staff mobile service units to help farmers with on site problems, a pest control programme, and a school lunch programme where students are supported to raise livestock and grow vegetables to support their lunch; a housewives group for food processing and product storage, and supporting organic groups in providing guidelines for correct procedure and get Q-Certificates.

OARDs in collaboration with DOAE decide research topics in consultation with farmers; and several research projects are implemented such as: Integrated Pest Management (IPM) and pest control and pest warning system, reducing pest outbreak, organic farming, apiary and honey processing, red azolla culture.

Kalasin Province officials' suggestions for future initiatives on attaining food security in the context of climate change included: shifting from rice to sugarcane farming; para rubber production; machine use; good agriculture practice (GAP); environmentally safe standard practiced in agriculture e.g. reduced use of agro-chemicals and herbicides.

Ubon Ratchathani Provincial officials, on the other hand, suggest the following strategies to cope with climate change and ultimately aim for long-term food security.

- To increase forest cover to 60 per cent,
- Storage of water at farm level by digging water harvest ponds,
- Change to growing crops which require less quantity of water,
- Off farm employment opportunities,
- Incentives to youths for motivating farming,
- Encouraging private sector involvement in farming to enhance economy of scale,
- Declaration of the whole province as an organic farming region,
- Control of new insects and pests,
- Setting up of local level (Tambon) pest forecasting unit, and
- Changing planting dates and techniques—ADAPT.

d. Viet Nam

Major issues for sustainable food security and poverty alleviation in the LMB region of Viet Nam include managing the irrigation systems built by the government, flood control and maintenance of effective drainage systems. In the immediate future recurrent floods and sea water intrusion will worsen the problems. Food security issues must be strategised in this context.

The government has already planned to change cropping patterns to deal with sea water intrusion by replacing rice-rice-rice cropping to rice-shrimp-rice in 100,000ha of such coastal farming areas. Similarly, in highland there is a plan in replacing coffee plantation which requires more water than other cash crops by pepper and cashew nuts.

Similarly, agricultural development programmes are developed based on agro-ecology. The majority of the poor live in the central highlands and there are programmes for poverty reduction and increasing income for sustained livelihoods. Coffee and cattle are the focus for such region. In the lower Mekong Delta, on the other hand, farmers are assisted in the development of their capacity through provision of training, technology, financing and linking them with the market and effective value chain.

Provincial, District and Local Level Programmes: The consulting team visited Dac Lak Province's Office under the Department of Agriculture and Rural Development (DARD) in Banmethout which is dominated by highlands.

The challenges faced by the province include:

(1) Since the value of agricultural produce and its GDP share is decreasing overtime but the share of industry is increasing, future focus should be on increasing quality of agricultural produce and link it with the value chain.

(2) There is a big problem in maintenance and operation of pumping stations and reservoirs. Additional resources are needed to maintain quality to reduce the risk of losing second crop during dry season.

(3) While the rainfall pattern is normal during April to November, the rainfall pattern is changing with heavy rain during December and January. This results in rise in the water level and agriculture production is affected. Therefore, there is a need to change to the short duration varieties. To deal with the prolonged drought period, drought resistant varieties need to be developed.

(4) For remote areas, since the farmers have very small areas for rice farming, it is essential to demonstrate model farms to increase productivity. Support for the provision of improved varieties of maize and soybean is equally important. In addition, training programmes to increase farmers' income, including cattle raising, and improvement programme for poor households is an important step for food security and poverty alleviation.

Food security issues are different in the case of plain areas of the Delta provinces in Southern Viet Nam. Government Decree # 45 of 2008 has placed the improvement of agriculture production improvement as top priority in Can Tho Province. This policy includes 100 per cent subsidy support for imported machines and 60 per cent subsidy to the locally manufactured and assembled machines, which are evidenced by the increased number of small tractors purchased and high demand for harvesting machines.

In order to get benefits from economies of scale, 2–3 farms are consolidated in one production unit in the province. This allows for mechanisation, increased labour productivity and insect pest control, and reduced environmental pollution.

For effective irrigation management, flood proofing of the primary canals are carried out regularly. Siltation and drainage facilities are improved, and dykes are constructed to protect agriculture land.

The overall effect of these efforts include: (i) increase in the number of crops planted, (ii) increase in productivity, (iii) introduction of new varieties and specialized agricultural extension services, (iv) decrease in cost due to subsidy in fertilisers and herbicides, and; (v) maximum potential yield realised due to 3 increase and 3 decrease strategy. The three decreases include reduced cost of variety and decrease use of fertiliser; reduced cost of irrigation water; and reduced post-harvest loss. The three increases in production include increasing commercial products, green mushroom growing and increased IPM practice to reduce insect-pest attack.

In Tra Vinh Province, both structural and non-structural measures are practised to cope with the negative effect of climate change. There are 132 km dyke systems in place and 90 km of them are sea dykes. Non-structural measure includes changing crop calendar and cropping pattern.

3. Pilot model application

3.1 Scope of exercises

Crop yield modelling, a simplest and best-established part in the process of food security modelling, was piloted in an easiest scale to learn lessons before building more extensive models. The amount of crop production results from a complicated and possibly iterative process that relies not only on the physiological mechanisms but also on the economic decisions of farmers. Because of this, there are two major approaches in crop yield modelling: statistic (econometric) and deterministic (or mechanical) models.

Crop growth models are widely used and produce precise crop yield responses to weather events. However, crop growth models require daily weather data and are calibrated under experimental conditions. Alternatively, regression analyses allow the quantification of weather changes on crop yields in an actual cropping context (Blanc 2012). In the following sections, one statistic and two deterministic crop yield models were built in a sub-national scale to see how well they can simulate the rice yield. Because future production and climate change impact on it are the primary concern, the modelling exercises cover up to generating and applying future climate scenarios.

3.2 About the models

Amongst the commonly used hydrological watershed models is the “Soil and Water Assessment Tool” (SWAT), a robust hydrologic model successfully employed in a number of watersheds. SWAT is a public domain watershed scale model developed by the Agricultural Research Service of the United States of America’s Department of Agriculture (USDA). The model was developed to predict the effects of land management on water, sediment, nutrients, pesticides, and agricultural chemicals in small to large complex basins.

The hydrological simulation of SWAT is based on water balance. The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soil. Runoff is predicted separately for each Hydrological Response Unit (HRU) and routed to obtain the total runoff for the watershed. This increases the accuracy and gives a good physical description for the water balance. The HRU process to calculate hydrological component is shown as below:

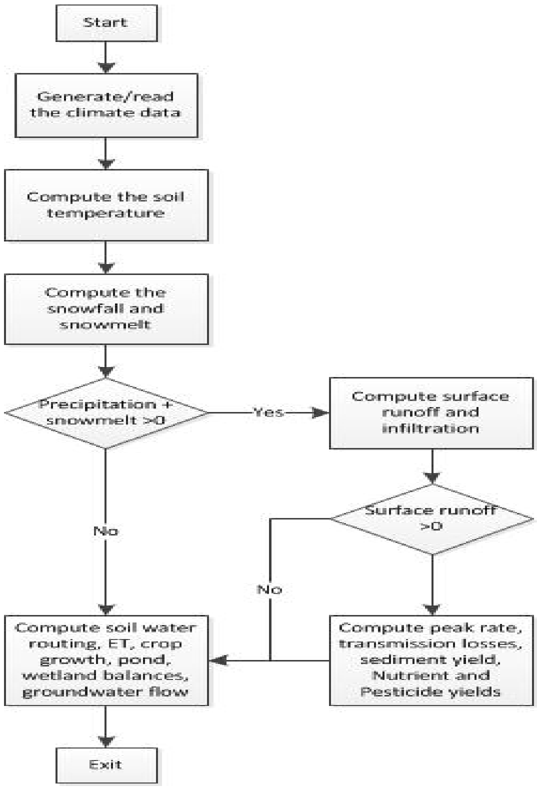


Figure 3.1a: SWAT flow to simulate the hydrological processes on the hydrological unit response (HRU)

DSSAT was developed by the International Consortium for Agricultural Systems Application, University of Hawaii, USA. The DSSAT model can predict the plant growth and yield based on the understanding of plants, weather, soil, and management interaction. Yield-limiting factors such as nutrient stresses (N and P), water stress, etc., are considered by the model. The DSSAT includes a suite of tools. The main tools include XBuild to create and modify experimental files, Weatherman for weather data, and SBuild for soil database, and GBuild for graphing outputs, which are available for data management and analysis (Hoogenboom et al. 2003). It is a process-based, management-oriented model that can simulate the growth and development of rice, which is affected by varying levels of water and nitrogen. The model can identify gaps between potential and on-station and on-farm yields.

3.3 Rice yield projection via econometric model

The future yields of rice, maize, cassava and soybean in Thailand were projected using an econometric model as given below;

$$Y_{it} = f\ (A_{it},\ T_t,\ T^2_t,\ P_{it},\ P^2_{it},\ T_t \times P_{it},\ T^2_t \times P_{it},\ T_t \times P^2_{it}) \qquad (4.1)$$

Where for each crop *i* at time *t*, Y represents yield, A area harvested, T temperature and P precipitation.

Quadratic terms for weather variables are included in the specifications to capture the non-linear weather effects on crop yields. Interaction terms between weather variables are used to determine the potential effect of one weather variable given the effect of the other weather variable. Data on weather indicators (mean annual temperature and annual precipitation) are obtained from the Meteorological Department of Thailand for the period of 1990-2012 (data is listed under annex-3). Yield and area data are log-transformed to improve the distribution of variables, so the model estimates elasticities. Weather variables, on the other hand, are not log-transformed so as to produce semi-elasticities, which allow direct determination of the impact of, say, a 1°C increase in temperature or a 10 mm increase in rainfall. Time trend variable is included in the model to capture the effect of technological changes over time on crop yields.

The regression results for rice, maize, cassava and soybean in Thailand are presented in Table 3.1.

Table 3.1: Parameter estimates for rice, maize, cassava and soybean in Thailand

Independent Variables	Rice	Maize	Cassava	Soybean
Constant	0.0544	0.0469	0.0761	0.0461
ΔlnA	-0.0268	0.0251	0.7887	-0.0202
T	0.0695	-0.0380	0.0153	0.0614
T^2	-0.0562	0.1262	-0.1172	-0.0438
P	0.0001	-0.0000055	-0.000081	-0.000034
P^2	-0.0000005	0.00000065	-0.0000008	-0.0000007
TxP	-0.0003	0.0005	-0.0003	0.0001
T^2xP	0.0004	-0.0012	0.00082	-0.00042
TxP^2	0.000001	-0.0000038	0.0000014	0.00000056
Trend	-0.0025	-0.0023	-0.0034	-0.00006

Dependent variable is ΔlnY. ΔlnA represent log-transformed change in area under the crop for a particular year. T and P are the average annual temperature and annual precipitation respectively.

The projected yields of rice, maize, cassava and soybean in Thailand for 2025 and 2050 based on the above estimations are presented in table 3.2.

Table 3.2: Crop Yields Projection for 2025 and 2050 in Thailand

Year	Rice	Maize	Cassava	Soybean
2025	-0.0412	-0.0260	-0.0357	0.0113
2050	-0.1041	-0.0836	-0.1200	0.0098

Rice yield is projected to decrease by 4 per cent in 2025 and 10.4 per cent in 2050. Largest decline is projected for cassava yield in 2050 (12 per cent decline as against the base period 1990-2012). Yield of soybean in Thailand is expected to slightly increase by 2025 and 2050. However, the per cent increase in soybean yield in 2025 (1.13 per cent) is slightly higher than that of 2050 (0.09 per cent) which indicates the yield is declining over long run.

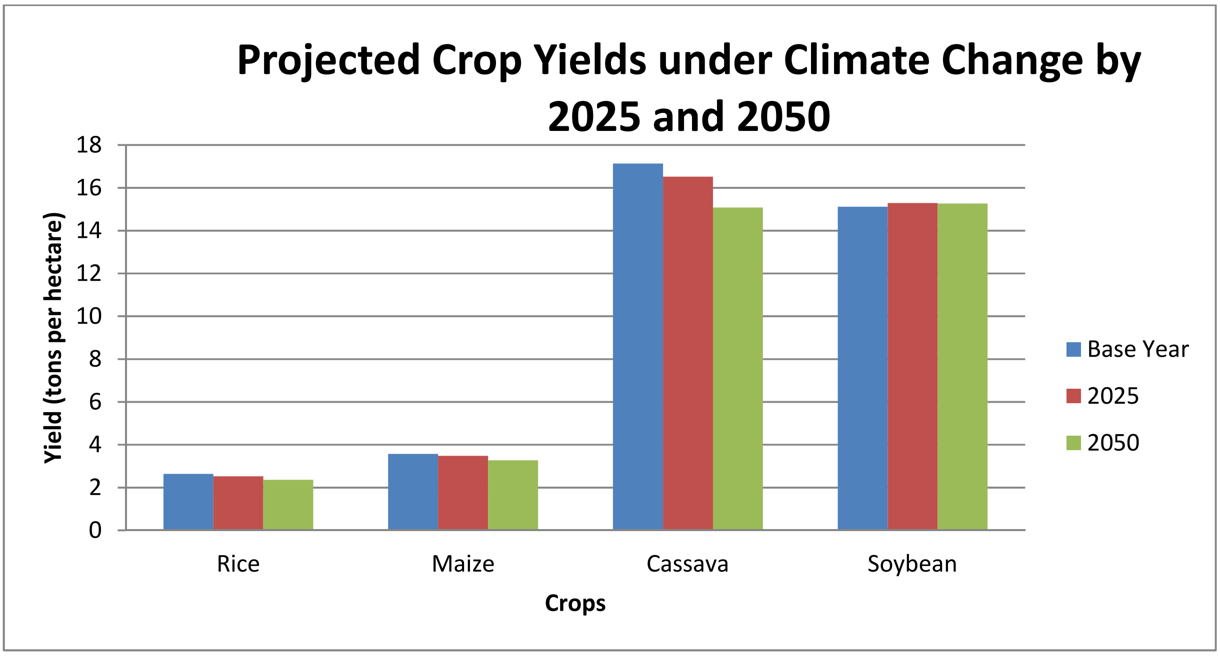


Figure 3.1b: Projected Yields under Climate Change by 2025 and 2050

3.4 Assessment of rice yield using SWAT model

The rice yield for Northeast Thailand was simulated by using the ecology specific data under SWAT model. Three different future time period, 2020–2029, 2050–2059 and 2080–2089, were chosen for the future projection and climate change impact assessment in three provinces of Northeast Thailand.

SWAT can simulate the hydrological process (stream flow), soil carbon, crop production and water quality. In this study, only stream flow and crop production was extracted from the model. The SWAT model was calibrated for both stream flow and crop production, and using the temperature and precipitation from the downscaling process.

The process to simulate the hydrological processes and crop assessment under a climate condition using the SWAT model is described as follows:

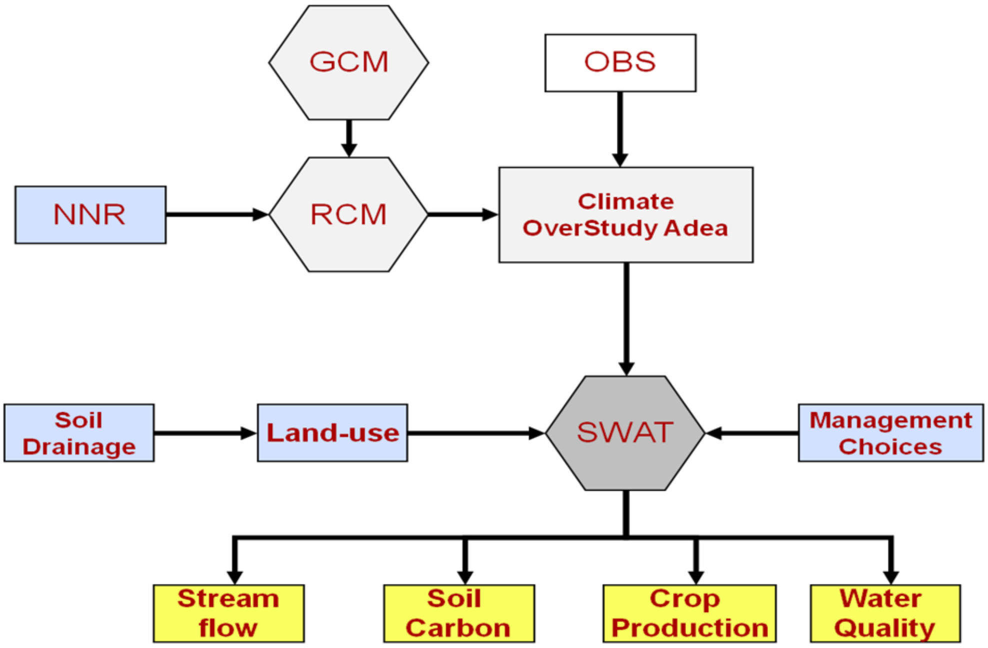


Figure 3.2: SWAT processes flow on simulating hydrological process and crop production

3.4.1 Study area

The studied basin comprises almost 19 provinces located in Northeast Thailand. These provinces lie between latitude 14.5 to 17.5 N and longitude 102.12 – 104.9 E. average temperature in the region ranges from 19.6 0C – 30.2 0C. Mekong River enters to the area after running along the borders of Lao-PDR; run along Thailand border in Eastern part of the country and then runs to Cambodia.

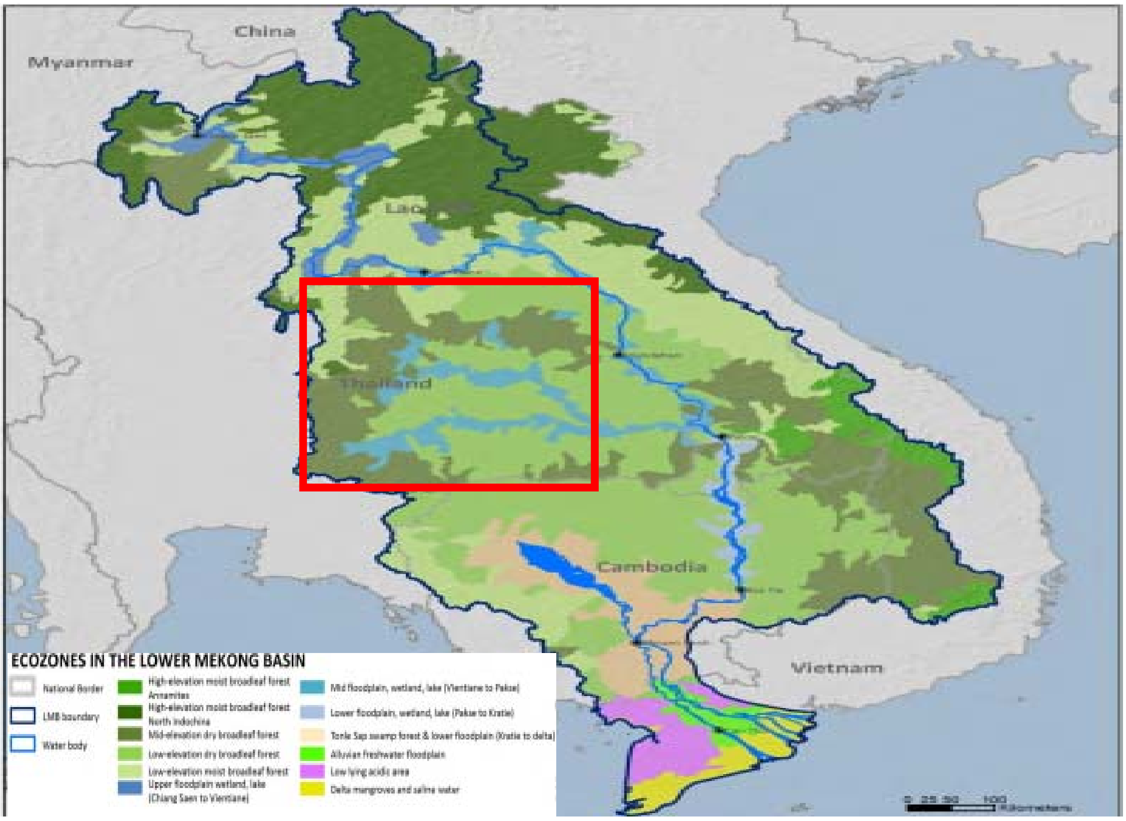


Figure 3.3a: The location map of study area

The three Provinces—Khon Kaen, Roi Et, and Ubon Ratchathani—in Northeast Thailand, were selected for this study because they represent the different regions in that part of the country as shown in Figure 3.3a. The two major Rivers namely the Chi and the Mun Rivers, which are also tributaries of the Mekong River, flow through these Provinces.

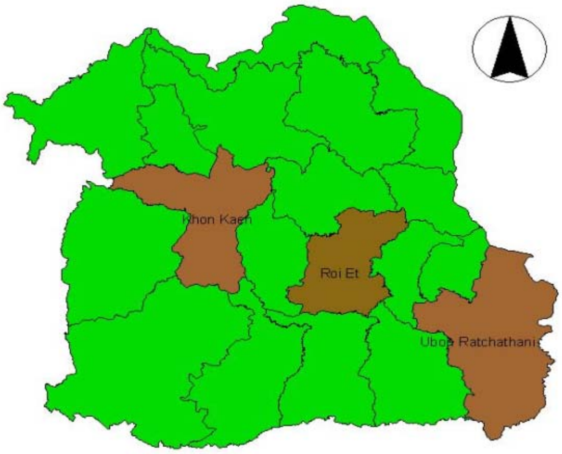


Figure 3.3b: Location of three study Provinces in Northeast Thailand

3.4.2 Data collection and crop modelling

This study required several data items, which include topographic (Digital Elevation Model or DEM), soil, land use, meteorological, hydrologic (stream flow) and agronomic data. The DEM was extracted from the U.S. Geological Survey with the resolution of 90m. The soil data was extracted from the FAO global soil database as well as the land use data. The data has been extracted for the study area and processed using the ArcGIS9.3.

The future climate dataset and agronomic data were collected from previous research (from Agarwal, 2010 and Babel et al, 2011). Agronomic data on the effect of planting dates, fertiliser application, rain fed versus irrigation watering, management practices, etc., and on yield and yield components, were retrieved from field experiments conducted by the Rice Research Center in Khon Kaen, Roi Et and Ubon Ratchathani. The cultivars used in the field experiment are KDML105 and RD6 in Roi Et province in 2004, and KDML105 in Roi Et and Ubon Ratchathani in 1996.

The information on the physical and chemical properties of the soil was collected from the Land Development Department (LDD). There are 44 established soil types in

Northeast Thailand. The major soil types used for rice cultivation are Roi Et, Ubon, Udon, Renu and Si Thon (LDD 2003). The soil type data collected for modelling include slope, runoff potential and drainage type, soil texture and the soil water capacity.

Table 3.3: Crop growth characteristics and other input data for model calibration and validation, Rice Research Center, Ubon Ratchathani. NPK: relative concentrations of nitrogen, phosphorus and potassium; DAS: days after sowing

	Calibration	Validation
Seeding date	8 Aug 1996	28 Aug 1996
Transplanting date	5 Sep 1996	26 Sep 1996
Plant density (m-2)	27	27
Flowering date	3 Nov 1996	18 Nov 1996
Treatment	Rain fed	Rain fed
Fertiliser application	(Mixed NPK 16:16:8)	(Mixed NPK 16:16:8)
	96 kg ha-1 31 DAS	96 kg ha-1 31 DAS

After Babel et. al., (2011)

Figure 3.4 below is the methodology adopted for generating climate change scenarios (future climate) and crop yield forecasting in the study area.

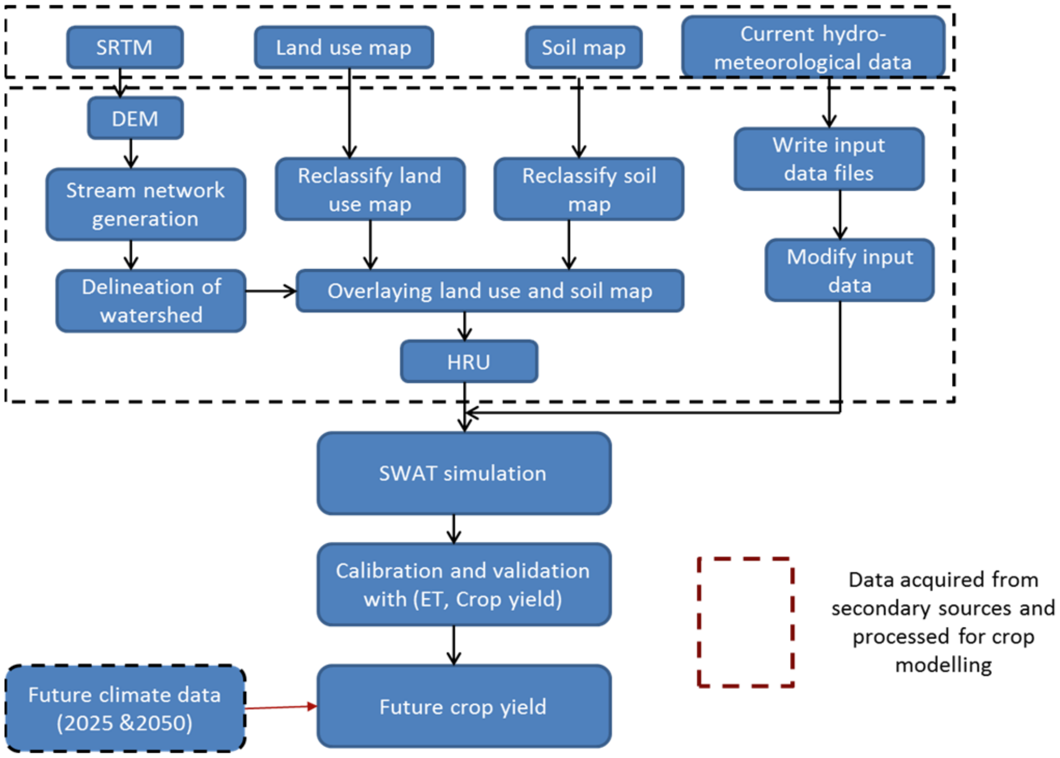


Figure 3.4: Illustration of flow chart for input data preparation and SWAT modelling for crop yield forecasting in the study area. Black dotted box represents of using secondary data.

3.4.3 Creation of climate change scenarios

Future climate scenario constructed by Southeast Asia START Regional Center at Chulalongkorn University, Thailand was used as the input to the SWAT model for forecasting future rice yield. The future climate was predicted using the Global Circulation Model (GCM) ECHAM4 developed for the global resolution of 280 x 280 km by Max Plank Institute, Germany. These data were developed with consideration of world growth forcing a level of atmospheric CO2 according to the IPCC SRES A2 scenario. The A2 scenario which is one of the most pessimistic scenario, describes the future world as very heterogeneous with regionally oriented economic development. Thus A2 scenario assumes a large increase in greenhouse gas emissions and thus significant negative impacts on climate. To increase the resolution from global to local extent, dynamic downscaling using regional climate model (RCM) was applied. The GCM output was further downscaled at the regional level using the RCM PRECIS (providing regional climates for impact studies) for the study area at 25 × 25 km. The downscaled data for the periods of 2020–2029, 2050–2059 and 2080–2089 for the grid that includes the study site were used for each of the three study sites respectively located in 3 provinces.

The predicted future climate scenario was applied to the calibrated SWAT model for the study sites to estimate the rice yield during the 3 future periods. The impacts were then assessed by computing the changes in the yield averaged for each of the 3 future decades (2020–2029, 2050–2059 and 2080–2089), with respect to the yield obtained for the actual daily weather data collected for 10 consecutive years from 1997 to 2006 for each of the 3 sites.

3.4.4 Calibration and validation

The calibration process was done by following the procedure by Santhi et. al (2001).
The model was calibrated for the period of 1981–1990 and followed by the calibration for the period of 1991–2006. The calibration parameters were constrained with the range of each parameter. Model outputs were calibrated to fall within the percentages of average measured values; and then monthly regression statistic, Nash–Sutcliffe Efficiency coefficient (ENS), and the coefficient of determination (R^2) were evaluated. If measured and simulated mean values met the calibration criteria but ENS and R^2 did not, then additional checking was performed to ensure that rainfall variability and plant growing season were properly simulated overtime. If all the parameters were pushed to the limit of their range for the model output, and the calibration criteria were still not met, then the calibration was stopped for that output.

Streamflow was the first output to calibrate. The streamflow was extracted as the surface runoff (SR) and base flow (BF). SR was calibrated until the average simulated and observed SR has the bias within 15 per cent and the monthly ENS > 0.5 and R2 > 0.6 (Santhi et al, 2001). The same criteria were applied to calibrate the baseflow. The procedures of the calibration are shown as follows:

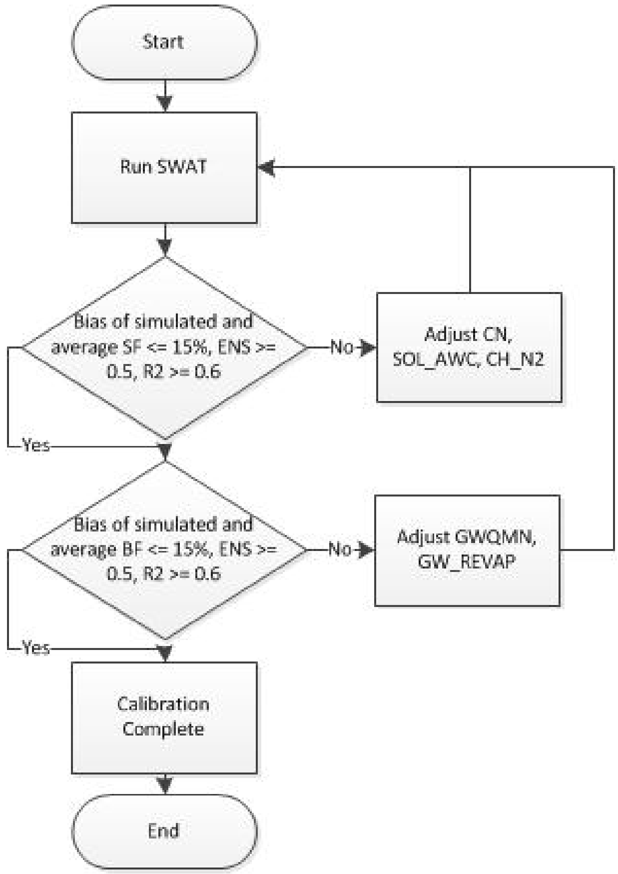


Figure 3.5: Calibration procedures of SWAT model

In the validation processes, the model was run with the parameters identified in the calibration process for different time series data from the calibration period. On the hydrological component, the average streamflow, peak flow and volume was between the observed and simulated and the statistic value of Nash–Sutcliffe Efficiency coefficient (ENS) and the coefficient of determination (R^2) was calculated.

For the crop model component, since the availability of crop production data is limited, the model was calibrated based on the result of field experiment in 1996. The simulated crop production was compared with the experiment result and the statistic value (coefficient of determination and bias) was calculated.

3.4.5 Stream flow

The simulated streamflow agreed with the observed value with the accuracy about 77 per cent. The simulated flow was substantially underestimated for September–October, but has the high accuracy for other months. The simulated monthly flow of the SWAT model reached the R^2 of 0.78 and Ens = 0.85.

In the validation period, the predicted peak flows and the time to peak matched well with the observed value. Though the peak flow in October was underestimated, the result shows close correspondence. The simulated flow shows good agreement with the observed data with the value of r^2 =0.82 and E_{ns}=0.887.

In most cases, monthly stream flows were reasonably predicted by SWAT for the study area during calibration and validation periods. However, stream flows were quite underestimated in the wet months through the period of study. Please refer to Annex-4 for details.

3.4.6 Rice yield

Rice yield was simulated with SWAT model. Data from three locations (Khon Kaen, Ubon and Roi Et) were used to calibrate the model. The results show that rice is simulated with r = 0.71 along the calibration periods (Figure 3.6). However, the model slightly over predicted the yield in Khon Kaen and Udon provinces where models slightly underestimated the yield in Roi Et province.

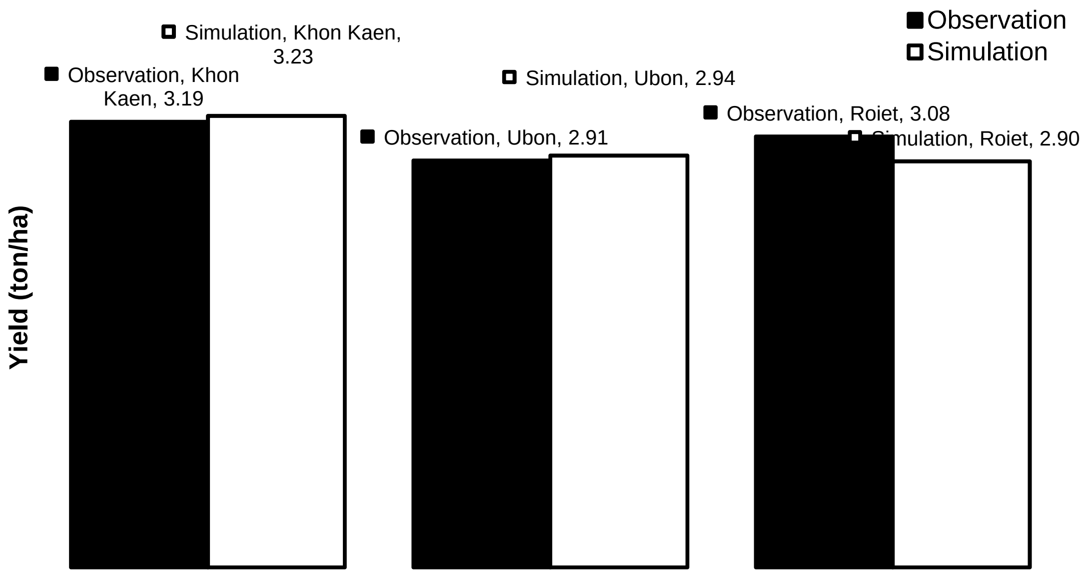


Figure 3.6: Observed and simulated rice yield in Khon Kaen, Ubon and Roi Et provinces during calibration

The observed and simulated yield at Ubon Ratchathani indicated the model results are in agreement with the observed data. Calibration was done for the seeding in the normal date (8 August 1996) and a later date (28 August 1996). The yields were simulated with the bias of 1.3 per cent in Khon Kaen, 1.24 per cent in Ubon and -5.7 per cent in Roi Et. However, the error is still acceptable and the model was used to project future rice yield in the following section.

3.4.7 Future climate projection

The projected future change of carbon dioxide concentration, precipitation, maximum and minimum temperature average for the decade for the provinces of the study area for the periods of 2020-2029, 2050-2059 and 2080-2089 as relative to baseline (1980—1990) are shown in the table below;

Table 3.4: The increasing of temperature and precipitation of future climate projection based on baseline (1980-1989)

Period	CO_2 (ppm)	Ubon Tmax (°C)	Ubon Tmin (°C)	Ubon Precipitation (%)	Khon Kaen Tmax (°C)	Khon Kaen Tmin (°C)	Khon Kaen Precipitation (%)	Roi Et Tmax (°C)	Roi Et Tmin (°C)	Roi Et Precipitation (%)
2020-2029	437	1.47	0.93	10.1	0.32	2.14	5.9	0.35	2.21	19.2
2050-2059	555	1.72	2.14	45.2	3.3	3.15	2.6	1.59	3.2	40.5
2080-2089	732	3.51	3.06	2.98	3.25	5.19	5.2	3.2	5.1	20.1

Sources: Babel et. al. (2011)

The result of future climate projection shows that the temperature will increase in the future in all locations and all time periods. However, the variation of temperature in the future at Ubon will be higher than two other areas (table 3.4). On the other hand the precipitation will increase at all areas. The precipitation will increase higher in the near future but lower in the far future.

3.4.8 Future crop yield under climate change scenario

The future crop is estimated by applying the projected future climate as inputs to the model. To assess the impact of climate change on future crop yield, future land use is assumed to be the same with the current period. The result of future projection is shown in the figure below.

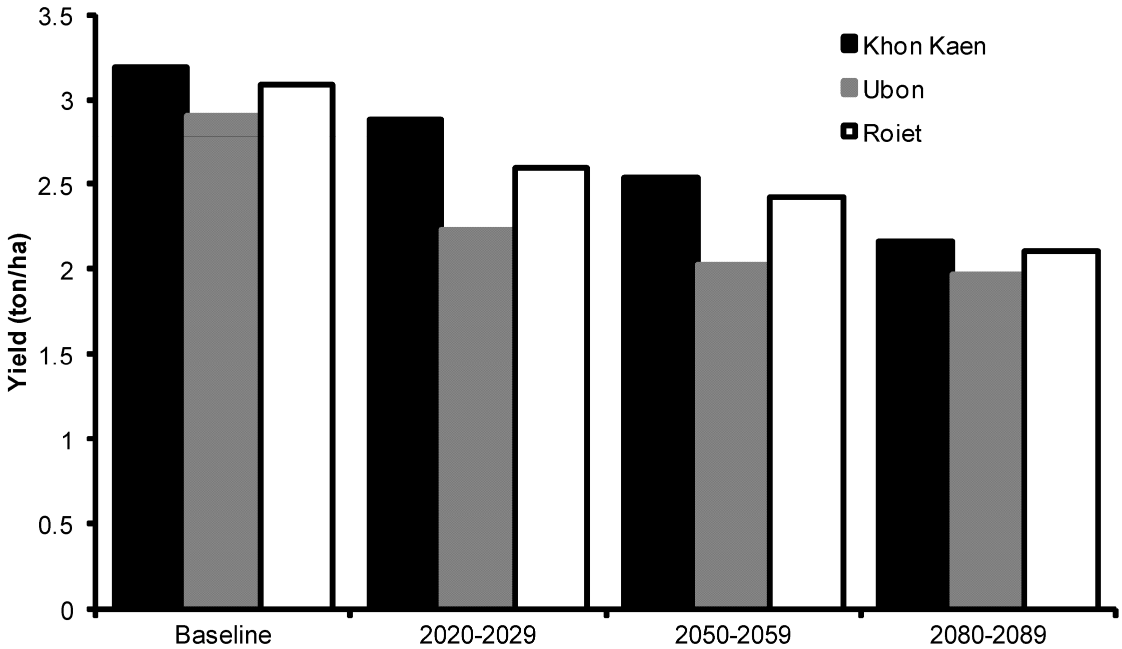


Figure 3.7: Rice yield in Khon Kaen, Ubon and Roi Et provinces under future climate scenarios

Table 3.5: Simulated and percentage change of rice yield under future climate change scenarios

	Rice Yield (tonne/ha)			
Location	**Baseline**	**2020-2029**	**2050-2059**	**2080-2089**
Khon Kaen	3.186	2.876	2.544	2.165
		(-9.73)	(-20.15)	(-32.05)
Ubon	2.908	2.233	2.027	1.975
		(-23.22)	(-30.3)	(-32.1)
Roi Et	3.081	2.597	2.426	2.104
		(-15.7)	(-21.26)	(-31.7)

The simulated rice yield is shown in the Table 3.5. The result shows the reduction of yield in all location about 9–24 per cent in the period of 2020–2029. The percentages of reduction will increase to the range of 20–30 per cent and 31–32 per cent respectively in the period of 2050–2059 and 2080–2089. This reduction was caused by the rise in temperature, which would decrease the grain-filling duration. Increasing temperature will reduce the duration between anthesis and maturity in the future, which would affect spikelet sterility and, hence, reduce the final grain yield. The harvest index was also reduced for future periods (Babel et. al., 2011). This condition indicates that, although the total biomass yield remained almost the same, the grain yield will decrease significantly in the future periods.

3.4.9 Result summary

This sample study assessed the impact of climate change on rice yield in Northeast Thailand using SWAT model and PRECIS dynamic downscaling. The SWAT model simulates the water availability in the study area and the crop production using the Erosion-Productivity Impact Calculator (EPIC) plant growth model. The simulated weather data downscaled via RCM PRECIS was in good agreement with the observed weather in terms of seasonal pattern, indicating that PRECIS provided acceptable weather data for future periods. The results show the increasing temperature and decreasing precipitation in future periods. It predicted that rice yield will decrease in the future. The results of the study provide a useful input to effective planning of water resources of the study area.

The simulated yields of rice in the three provinces of NE Thailand for 2020–2029 and 2050–2059 under SWAT model are in line with the projected rice yields for the entire Thailand using econometric model for the 2025 and 2050. The decline in the yield is higher under SWAT model showing about 9 to 24 per cent decline in the rice yield by 2020–2029 and about 20 to 30 per cent decline in rice yield by 2050–2059 compared to rice yield projection by the econometric model that indicates 4 per cent and 10 per cent decline in the yield by 2025 and 2050 respectively.

3.5 Assessment of rice yield using DSSAT model

The CERES-Rice model (Singh et al. 1993, Ritchie et al. 1998) available with the DSSAT Version 4.5 (Hoogenboom et al. 2003) was used in this study.

3.5.1 Study area

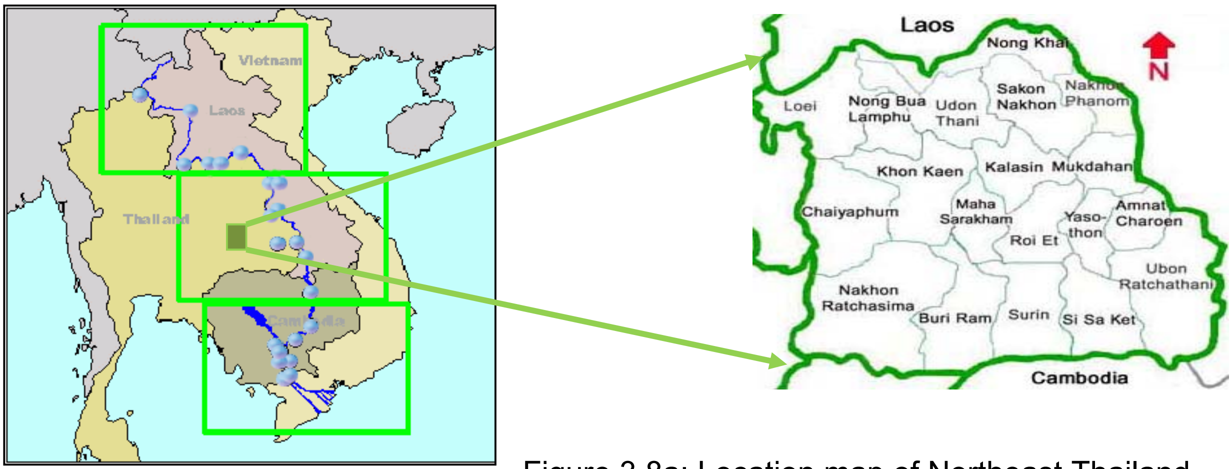


Figure 3.8a: Location map of Northeast Thailand

The three Provinces-Khon Kaen, Roi Et, and Ubon Ratchathani-in Northeast Thailand, were selected for this study.

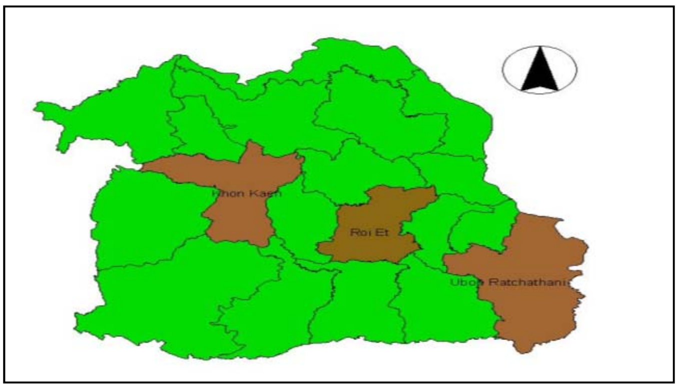


Figure 3.8b: Location of three study Provinces in Northeast Thailand

3.5.2 Data

Experimental Data for Rice Crop

Rice Research Centers located in Northeast Thailand conduct many experiments to improve crop production and productivity in the region. The details of some of the field experiments conducted by the Rice Research Centers were collected and used for DSSAT model calibration and validation.

Crop Genetic Coefficients

The genetic coefficients for the selected rice cultivars grown in North and Northeast Thailand were derived by Buddhaboon et al. (2004) and are presented in Table 3.6.

Table 3.6: Genetic coefficients of rice cultivars, KDML105 and RD6

Rice Cultivar	Genetic Coefficients							
	P1	P5	P2R	P2O	G1	G2	G3	G4
KDML105	502.3	386.5	1233.0	12.7	45.7	0.027	1	0.95
RD6	550.3	386.5	1243.0	12.8	48.7	0.028	1	0.95

Soil Data

The information about physical and chemical properties of the soil series in Northeast Thailand was collected from the Land Development Department, Bangkok, Thailand. The soil type data collected for this modelling included colour, slope, runoff potential, drainage type along with layered classification of soil texture, pH, phosphorous, potassium, carbon, nitrogen, and cation exchange capacity.

Weather Data

The weather data were collected from Thai Meteorological Department for the weather stations in Khon Kaen, Roi Et, and Ubon Ratchathani. Data of the weather station close to the experimental plot were used for this study. The daily weather data including rainfall, maximum and minimum temperatures, sunshine hours, wind speed, and evaporation were collected for the period of 1980–2007.

Future Climate Data

The future climate data for this study were used from Hadley Centre Coupled Model, version 3 (HadCM3) for two IPCC SRES scenarios B1 and A2. The GCM data is available from the IPCC data distribution centre (IPCC-DDC) website. The emission scenarios were selected based on their assumptions of future projections. The A2 scenario is one of the most pessimistic scenarios, as described earlier. The B1 scenario is the most optimistic scenario which assumes a sustainable development path to be followed in the future. As per B1 scenario, the emphasis in future is on global solutions to economic, social, and environmental sustainability, without additional damages to the climate. The low resolution climate data from the GCMs were downscaled for the study region using statistical downscaling model LARS-WG. The data for GCM HadCM3 for two scenarios B1 and A2 are available in model LARS-WG 5 database. The data for the grids under which the study Provinces exist were used in this study.

The focus of this study was to analyse the impact of future climate change on rice yield. The basic steps involved in the study are shown in Figure 3.9. The major steps involved were the selection of study area followed by the secondary data collection on soil, weather, and crop characteristics. The secondary data compiled from agronomic experiments conducted at Rice Research Centers in Northeast Thailand and available in Agarwal (2008), were used as a reference. The experimental data for the crop along with additional data for climate were then analysed and used to develop the latest version of crop growth model DSSAT 4.5. The low resolution climate data were downscaled for the study sites using statistical downscaling model. Thus both crop growth model DSSAT and climate downscaling model LARS-WG 5 were calibrated and validated again for this study. The downscaled future climate data were used to simulate rice yield in future periods.

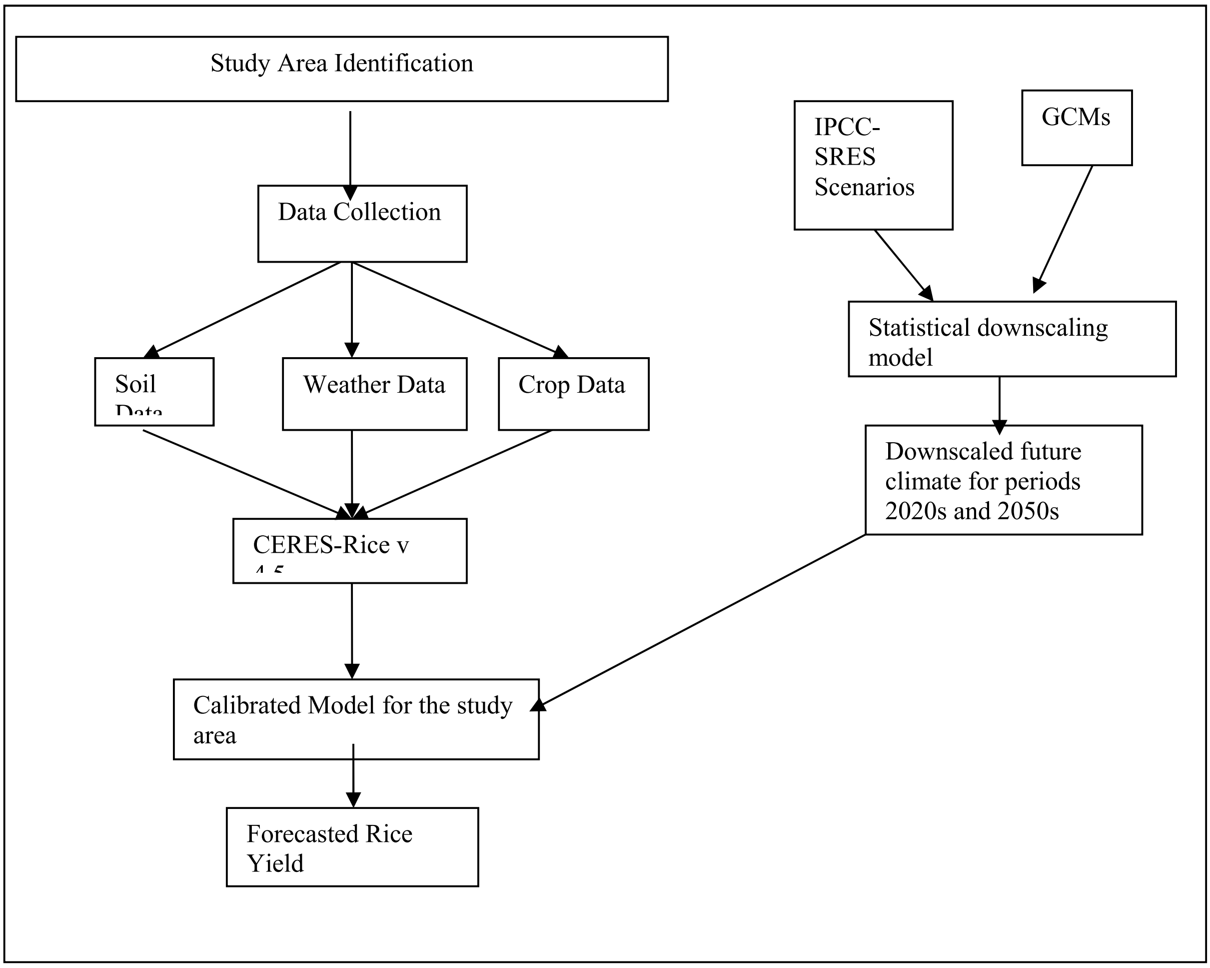


Figure 3.9: Research methodology flowchart

The data obtained from the field experiments conducted by the Rice Research Centers in Ubon Ratchathani, Roi Et, and Khon Kaen for crop growth characteristics, i.e. flowering day, maturity day, grain yield, and harvest index, were compared with the simulated results for the model calibration and validation. The model was further evaluated by using the observed and simulated weather data for 1981–2000 as an input to the calibrated model and comparing the simulated yields at the three locations with the observed yields.

3.5.3 Creation of climate change scenarios

To incorporate changes in climate variability and generate scenarios, the relative change between the GCM baseline period and the GCM future scenario were calculated. Parameters calculated here were: relative change in wet series (length of monsoon period) and dry series length (non-monsoon period); relative change in mean temperature, standard deviation for each month; and mean changes in precipitation amount, mean temperature, and solar radiation for each month. The changes in mean temperature are additive changes, and changes in monthly precipitation, length of the wet and dry spells, and temperature standard deviation are multiplicative. These parameters are then applied to the generated synthetic weather data for the baseline period, and the modified synthetic data are used as the future climate data for the station.

The predicted future climate scenario was applied to the calibrated CERES-Rice model for the study sites to determine the impacts on rice yield during the three future periods. The impacts were then assessed by computing the changes in the average yield of the future periods with respect to the yield obtained for the simulated daily weather data for the baseline period.

3.5.4 Calibration and validation

For development of the DSSAT model, the experimental data collected from research stations along with soil data, daily weather data, and rice genetic coefficients were used as input parameters. The parameter used for the model calibration was initial crop residue in the field. The yield components considered for the model calibration were flowering day, harvest index, and grain yield. The percentage error within the range of 10 per cent was considered as satisfactory for the model calibration. The comparisons of observed and simulated values at various sites are discussed below.

3.5.5 Roi Et for Cultivar RD6

The DSSAT model was used to simulate the yield of rice variety RD6 in Roi Et Province. Three different applications of fertilisers were considered for yield simulation, the first, mentioned as RE1, in which N fertiliser @ 376 kg/ha was applied, in the second, RE2, no fertiliser was applied, and in third, RE3, N fertiliser @ 156 kg/ha was applied. Similar experiments were conducted in 2004 at Roi Et by the Rice Research Department (RRD). The model simulated yield was compared with the yield observed in the field during experiments by RRD. The yield simulated by model was in close agreement with the observed value as indicated in Table 3.7, and also the simulated and observed yields are shown in Figure 3.10 for different fertiliser treatments. The percentage error between simulated and observed yield for treatment using 376 kg/ha of fertiliser was 6.5 per cent, while for harvest index it showed an error of 0.09 (26.5 per cent). In the case of treatment without fertiliser, the grain yield was simulated with an error of 5.7 per cent and 0.03 (6.3 per cent) in harvest index. For application of 156 kg/ha of fertiliser, which was the recommended rate of RRD, the error was 3.5 per cent in grain yield and 0.07 (15.9 per cent) in harvest index. The results in Table 3.7 also indicated that the rice yield was maximum when the fertiliser application rate was 156 kg/ha. The error in simulated and observed value of physical maturity day was high compared to other two parameters. The percentage errors between the observed and simulated yields ranged from 3.5–6.5 per cent, whereas the percentage errors between the observed and simulated harvest indices were 6.3–26.5 per cent. The errors up to 15 per cent are considered acceptable for yield modelling studies. Soler et al. (2007), who used the DSSAT CERES-MAIZE model to estimate actual yields of rain fed and irrigated maize genotypes, in the state of São Paulo, Brazil reported percentage errors in the range from –10.7 to 11.3 per cent. It is important to note that the models used in this study accounted only for the effect of weather variables such as solar radiation, photoperiod, temperature, and rainfall. Other factors such as the occurrence of pests, diseases, and nutritional deficiency were not considered in the field trials. These might explain part of the bigger errors (>15 per cent) observed in two cases for the harvest indices.

Table 3.7: Observed and Simulated Yield Components for the Experiment at Roi Et for Cultivar RD6

Fertiliser 16-16-8	Grain Yield (kg/ha)			Harvest Index			Physical Maturity Day		
	Sim	Obs	% error	Sim	Obs	% error	Sim	Obs	% error
376 kg/ha	3081	3280	6.5	0.34	0.43	26.5	236	183	–22.5
0 kg/ha	2734	2890	5.7	0.48	0.51	6.3	158	183	15.8

156 kg/ha	3314	3430	3.5	0.44	0.51	15.9	158	183	15.8

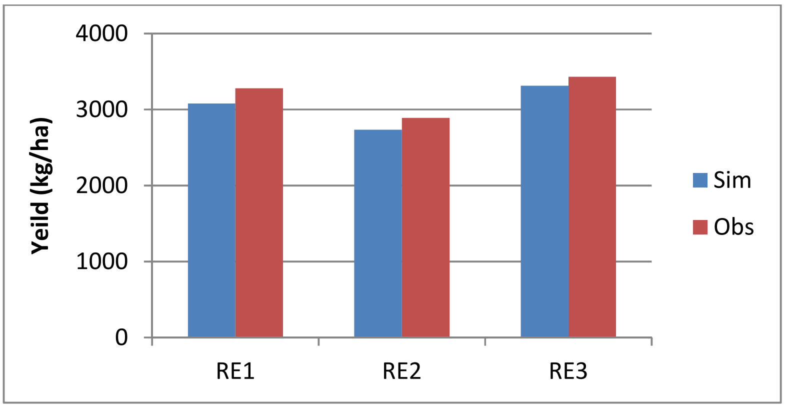


Figure 3.10 Simulated and observed yield for RD6 at Roi Et

3.5.6 Roi Et for Cultivar KDML105

The DSSAT model was used to simulate the yield of rice KDML105 in Roi Et Province. Two treatments of fertiliser application were analysed, the first without using any fertiliser and the second using fertiliser @ 157 kg/ha. This experiment was also conducted by RRD in Roi Et Province, and the model simulated results were compared with the observed yield parameters from the field. The results as presented in Table 3.8 indicated that the DSSAT model simulated the crop growth parameters satisfactorily with an error of 6.4 per cent in grain yield and 0 per cent error in harvest index in the condition without using fertilisers. In the simulation using fertiliser 157 kg/ha, the yield was simulated with an error of 0.5 per cent and harvest index had an error of 0. The physical maturity day was also simulated satisfactorily in both experiments. The results for simulation of two varieties RD6 and KDML105 also indicated that the yield of KDML105 in Roi Et was much less than the yield of RD6. Also the yield data for Northeast Thailand showed that the yield of KDML105 in Roi Et was much less than the average yields of KDML105 in Northeast Thailand. This may be due to soil and weather conditions which do not favour KDML105. On the other hand, RD6 performed much better in this region, so it can be inferred that this location was more suitable for RD6 then KDML105.

Table 3.8: Observed and Simulated Yield Components for the Experiment at Roi Et for Cultivar KDML105

	Grain Yield (kg/ha)			Harvest Index			Physical Maturity Day		
	Sim	Obs	% error	Sim	Obs	% error	Sim	Obs	% error
No fertiliser	1304	1220	–6.4	0.48	0.48	0.0	140	149	6.4
Fertiliser 16-16-8 @ 157kg/ha	1801	1810	0.5	0.39	0.39	0.0	157	149	–5.1

Drought Response experiments conducted at Ubon and Khon Kaen

In Ubon Ratchathani and Khon Kaen Provinces, the DSSAT model was used to simulate the rice yield under different conditions of irrigation practices. The conditions considered for this part of simulation were, fully irrigated at Ubon (Ubon1), rain fed (Ubon2), rain fed with late seeding (Ubon3), and rain fed at Khon Kaen (CP1). Similar experiments were conducted by RRD at their research stations located in the two Provinces. The model simulated yield parameters were compared with the observed values to analyse the performance of DSSAT. The simulated and observed values are presented in Table 3.9. The results indicated that the model simulated rice yield satisfactorily in all the cases with error varying in the range of 0–3.4%. The anthesis day and harvest index were also simulated satisfactorily with maximum error of 15.2% in harvest index for the case of late seeding in rain fed conditions. The observed and simulated yields in all four cases considered here are shown in Figure 3.11.

Table 3.9: Observed and Simulated Yield Components for the Drought Response Experiments at Ubon (URRC) and Chum Phae (CPRRC)

	Grain Yield (kg/ha)			Anthesis Day			Harvest Index		
	Sim	Obs	% error	Sim	Obs	% error	Sim	Obs	% error
Fully Irrigated at URRC	3883	3750	–3.4	78	77	–1.3	0.44	0.44	0.0
Rain fed at URRC	3360	3360	0.0	80	87	8.8	0.38	0.4	5.3

Rain fed with late seeding dates at URRC	2771	2720	–1.8	69	73	5.8	0.33	0.38	15.2
Rain fed at CPRRC	3045	2940	–3.4	93	85	–8.6	0.39	0.42	7.7

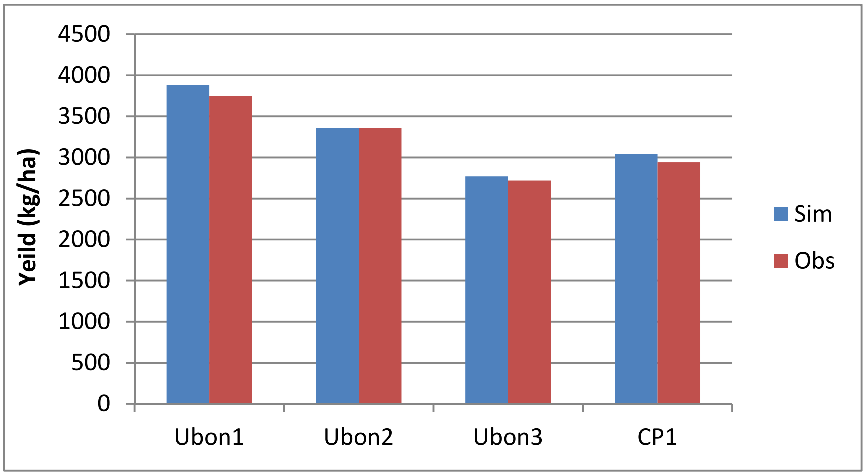


Figure 3.11 Observed and simulated grain yield for the drought response experiments at Ubon and Chum Phae

3.5.7 Future climate projections

The projections of future climates based on GCM HadCM3 under A2 emission scenario for Khon Kaen Province are presented in Figure 3.12 and under B1 emission scenario is presented in Figure 3.13. The change in Tmax, Tmin, and rainfall in three study sites for future period relative to the baseline period is presented in Table 3.10 for A2 scenario and in Table 3.11 for B1 scenario. The results indicated that the temperature is projected to increase in all three provinces during all months of the year. The change in temperature is almost similar under two scenarios (B1 and A2) during 2020s, but it shows significant difference during the later part of the century under the two scenarios. Rainfall is projected to decrease during early and mid-century periods, but increase during the late century period at all three study sites.

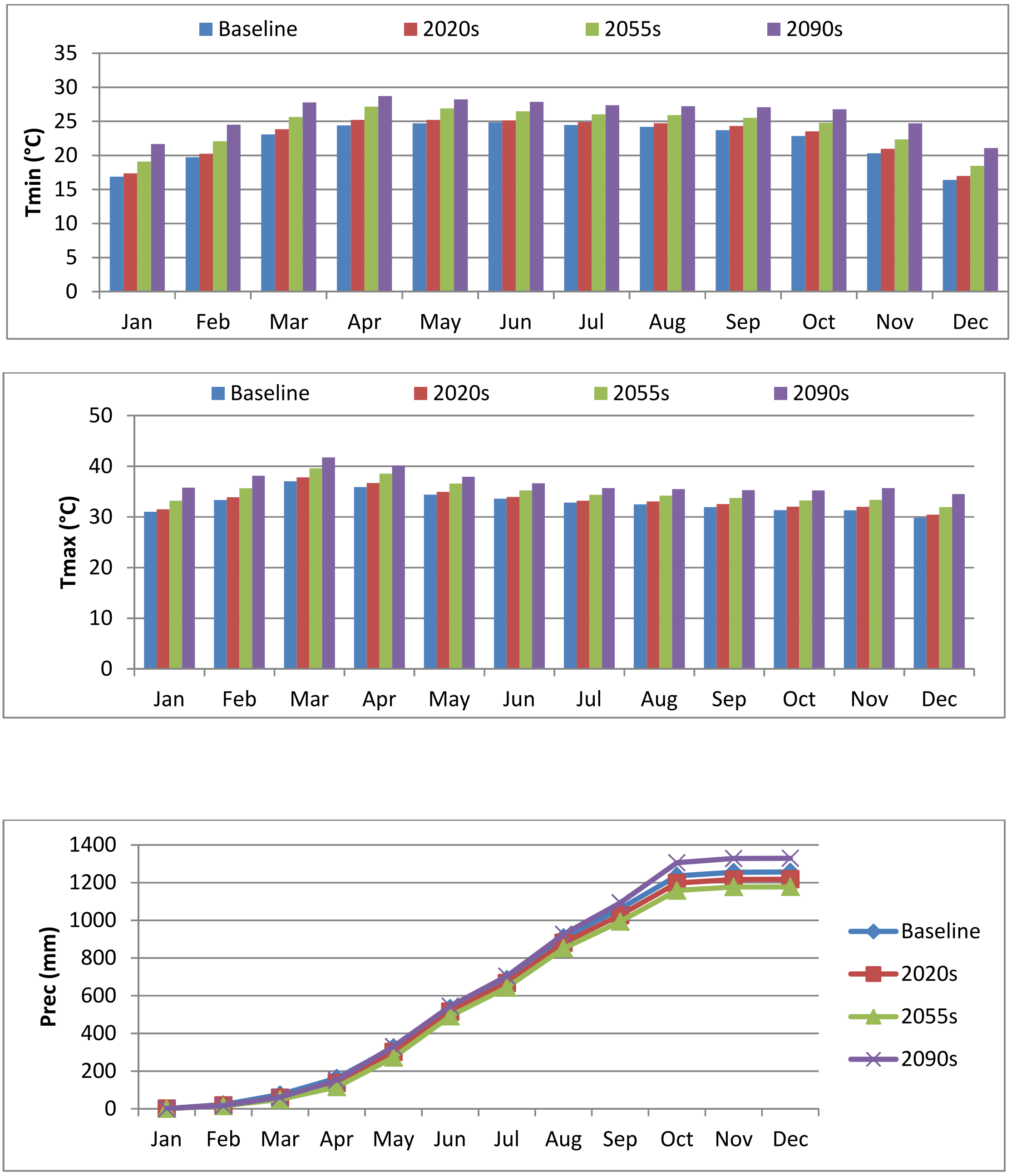
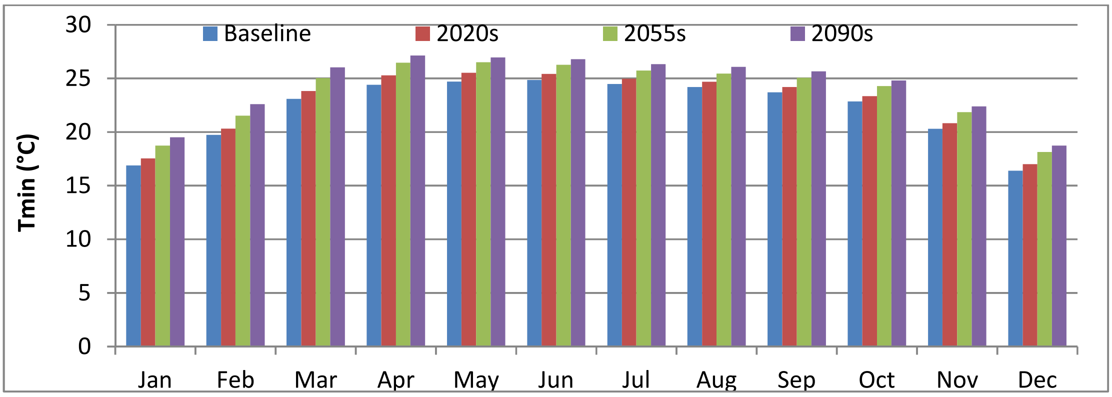
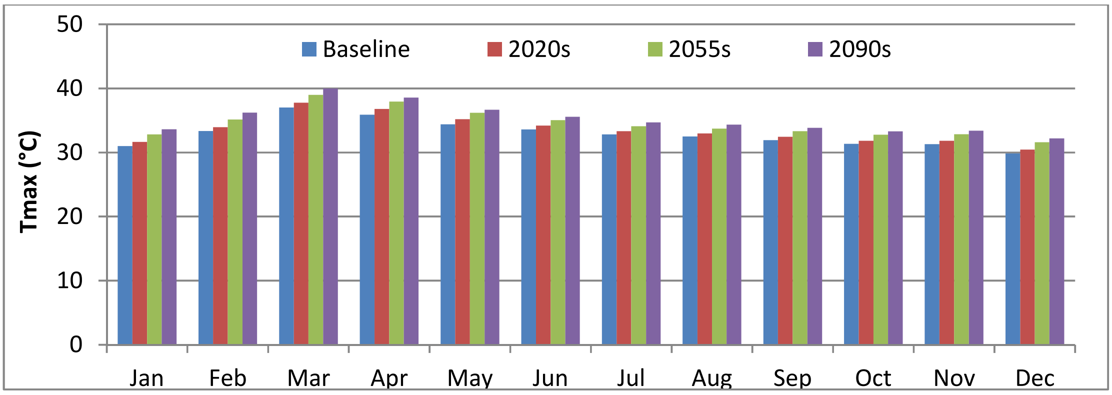


Figure 3.12 Mean monthly Tmin, Tmax, and rainfall as projected by HadCM3 under A2 scenario in the Khon Kaen during baseline and three future periods (2020, 2055, and 2090)





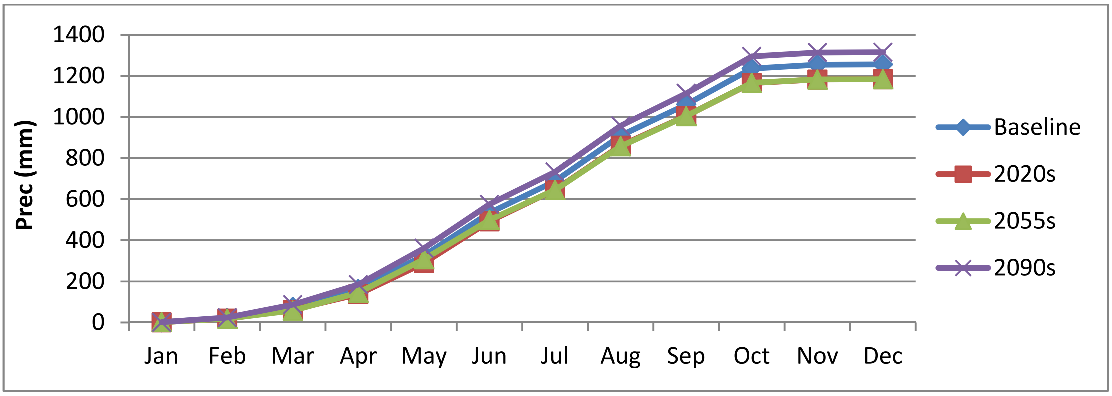


Figure 3.13: Mean monthly Tmin, Tmax, and rainfall as projected by HadCM3 under B1 scenario in the Khon Kaen during baseline and three future periods (2020, 2055, and 2090)

Table 3.10: Change in annual mean Tmax, Tmin, and rainfall as projected by HadCM3 under A2 scenario for future periods relative to the base period of 1981–2000

	Khon Kaen			Roi Et			Ubon Ratchasima		
Time Period	Tmax (°C)	Tmin (°C)	Prec (%)	Tmax (°C)	Tmin (°C)	Prec (%)	Tmax (°C)	Tmin (°C)	Prec (%)
2011-2030	0.58	0.57	–3.03	0.57	0.57	–2.63	0.61	0.56	–2.32
2046-2065	2.06	2.07	–6.23	2.07	2.07	–5.28	2.13	2.07	–5.89
2080-2099	3.95	3.95	5.81	3.92	3.91	4.29	3.90	3.85	3.08

Table 3.11: Change in annual mean Tmax, Tmin, and rainfall as projected by HadCM3 under B1 scenario for future periods relative to the base period of 1981–2000

	Khon Kaen			Roi Et			Ubon Ratchasima		
Time Period	Tmax (°C)	Tmin (°C)	Prec (%)	Tmax (°C)	Tmin (°C)	Prec (%)	Tmax (°C)	Tmin (°C)	Prec (%)
2011-2030	0.62	0.61	-5.77	0.61	0.61	-4.77	0.65	0.60	-5.35
2046-2065	1.62	1.62	-5.77	1.62	1.62	-5.18	1.64	1.60	-4.08
2080-2099	2.28	2.29	4.69	2.27	2.27	4.57	2.27	2.22	4.61

3.5.8 Impact on rice yield

The rice yield was projected using the downscaled GCM data for the three future periods. The projected yields are presented in Table 3.12 for HadCM3 A2 scenario and in Table 3.13 for HadCM3 B1 scenario. Based on the climate projections for HadCM3, both A2 and B1 scenarios, the rice yield is projected to change by a small amount during early and mid-century period in all three Provinces. The yield is projected to decrease by 6.1, 1.3, and 7.8% under A2 scenario during the late century period in Khon Kaen, Roi Et, and Ubon Ratchathani Provinces, respectively. Under B2 scenario, change in yield does not show any clear pattern of increase or decrease. In a similar study by Babel et al. (2011), significant decrease in yield was projected (Table 3.14) based on the climate change projections from ECHAM4 GCM.

Table 3.12: Simulated rice yield and changes (%) for future periods based on HadCM3 simulated climate under A2 scenario

Location	1981-2000	2011-30		2046-65		2080-99	
	Yield (Kg/ha)	Yield (Kg/ha)	% change	Yield (Kg/ha)	% change	Yield (Kg/ha)	% change
Khon Kaen	4495.7	4428.8	–1.5	4500.3	0.1	4222.5	–6.1
Roi Et	2191.9	2175.1	–0.8	2196.6	0.2	2163.8	–1.3
Ubon	2885.0	2878.3	–0.2	2813.5	-2.5	2659.0	–7.8

Table 3.13: Simulated rice yield and changes (%) for future periods based on HadCM3 simulated climate under B1 scenario

Location	1981-2000	2011-30		2046-65		2080-99	
	Yield (Kg/ha)	Yield (Kg/ha)	% change	Yield (Kg/ha)	% change	Yield (Kg/ha)	% change
Khon Kaen	4495.65	4327.73	–3.74	4504.55	0.20	4561.15	1.46
Roi Et	2191.85	2178.87	–0.59	2202.55	0.49	2211.25	0.89
Ubon	2884.95	2901.80	0.58	2849.60	–1.23	2722.75	–5.62

Table 3.14: Simulated rice yield and changes (%) for future climate scenarios

Location	1997-2006	2020-29		2050-59		2080-89	
	Yield (kg/ha)	Yield (kg/ha)	Change (%)	Yield (kg/ha)	Change (%)	Yield (kg/ha)	Change (%)
Ubon	2732	2427	–11.16	2200	–19.47	1855	–32.10
Khon Kaen	2807	2101	–25.15	1883	–32.91	1901	–32.27
Roi Et	2128	1764	–17.11	1481	–32.11	1944	–8.64

Source: Babel et al. (2011)

3.5.9 Result summary

To assess the direction of climate change impact on rice production in the LMB, a sample study was conducted for the three Provinces of Northeast Thailand, where necessary data to simulate rice yields for future periods were accessible. The crop growth model CERES-Rice, which is a part of DSSAT, has been used for the simulation. The statistical downscaling model LARS-WG is used to downscale the low resolution GCM data for the study sites. The observed and simulated yields data at three sites indicate that the model results are in good agreement with the field observations. Thus, the calibrated CERES-Rice model can be used for forecasting rice yields for future periods. The observed and LASR-WG simulated minimum and maximum temperatures and rainfall for the baseline period are also in close agreement in terms of mean and R^2 values.

Future projections from HadCM3 GCM under A2 scenario downscaled for the three Provinces in Thailand indicate that the temperature is expected to increase in all three future periods. Rainfall is projected to decrease during early and mid-century, but may increase during the late century period. Rice yield is projected to decrease during all three periods although the percent decrease is very small during early and mid-century periods. Projections under B1 scenario do not show any clear pattern of increase or decrease in rice yields in any of the Province.

4. Toward an assessment of the conditions for long-term food security and poverty reduction

Literature review shows that food security becomes a predominantly rural and also local issue in the LMB, which is amongst the major food sources in the world. Food insecurity concentrates mainly in remote mountain areas with low levels of rice production in the LMB. Though food shortages would occur from a range of factors, local crop failures remain the key factor where limited access to markets and poverty remains significant. Where local crop failures threat food security, importance of capture fishery would hold as well.

Gross margin analysis of the cropping sector in major cropping districts of both upland and lowland, which covered both rain fed and irrigated rice, shows higher profits than those recorded in literature in general. Related information gained in the provincial offices and fields suggests the sector’s progress in market integration and reliance on non-family labour, agricultural machinery, and chemical inputs. Income gap between the rich and poor is claimed to be expanding in most locations, too. Food insecurity and poverty issues in these places need focus on marginalised people. In terms of long-term food security, the risk of modern farming practices may also need investigation.

Pilot exercises of crop yield modelling showed varied levels of future reduction in the yields in the projected climate scenarios. An econometric and SWAT models predict rather clear reduction in the rice yield, though the DSSAT model predicted minimal reduction. Historical records have stable increase so far. Combined with the result of gross margin analysis and observations in the field, actual trends of average rice yield will likely continue to increase in the near future. For the long-term insecurity, risks and vulnerabilities other than the direct impact of climate on plant physiology, also need investigation. Literature review on climate change impacts points out various risks in crop production that are not taken into account in the yield simulation by crop models.

An econometric model projects the future yields of upland crops somewhat mixed, while historical records are significantly variant. Historical records may reflect not only climate conditions but also agronomic response to market trends. Because farmers change which upland crops to plant and how intensively grow them based on not only land suitability but also their commercial values, comparison between econometric and mechanical crop models can be more meaningful for these upland crops than that of rice. Because upland crops may be more relevant to current hot spots of food insecurity and poverty, such studies are desirable for select locations. On the other hand, historical yield data represent those of commercial farming. Agronomic practices between commercial farmers in lowlands and subsistence farmers in mountainous localities may also be significantly different. As vulnerability comprises exposure, sensitivity, and adaptive capacities, detailed studies on food system in a local scale may be the priority for the current food insecure spots.

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Annex-1

Benefit cost analysis and Gross Margins of crops in the LMB

Net Returns and Gross Margin Analysis of Maize in the LMB (USD/ha)

Items	Vientiane (Lao PDR)	Battambang (Cambodia)	Battambang (Cambodia)	Dac Lak (Viet Nam)
Seed and Sowing Cost	720.48	83.2	61.32	149.58
Land Preparation Cost	318.79	64	51.53	142.01
Fertility Input Cost	191.28	23.23	63.79	165.68
Irrigation Cost	39.85	0	0	0
Cost of Plant Protection Measures	64.55	7.60	35.58	9.46
Harvesting and Threshing Cost	39.85	245.36	98.14	142.01
Marketing Cost	0	0	0	0
Total Cost	**1374.81**	**423.40**	**310.36**	**608.75**
Total Quantity (kgs)	5625	5000	2500	3047
Price (USD/kg)	0.28	0.22	0.22	0.21
Total Revenue	**1578.04**	**1104.14**	**552.07**	**649.06**
Net Profit	203.23	680.74	241.71	40.31
Benefit Cost Ratio	1.15	2.61	1.78	1.06
Gross Margin	0.13	0.61	0.44	0.06

The largest cost items in producing maize are the seed and sowing, fertility inputs and harvesting and threshing in the LMB. Direct sale of the product eliminates the marketing costs to increase the net revenue of the producers. The per hectare yields of maize in Vientiane (Lao PDR), CP QQQ and CP 888 varieties in Battambang (Cambodia) and Dac Lak (Viet Nam) are 5.6, 5, 2.5 and 3 tonnes respectively while the net profit or net revenue generated per hectare of maize production are US$203.23, US$680.74, US$ 241.71 and US$40.31 respectively. The gross margins for maize in the LMB show that farmers earn 13 per cent, 61 per cent, 44 per cent and 6 per cent profit on their investment in maize production in Vientiane (Lao PDR), CP QQQ and CP 888 varieties in Battambang (Cambodia) and Dac Lak (Viet Nam) respectively.

Net Returns and Gross Margin Analysis of Cassava in the LMB (USD/ha)

Items	Khampong Cham (Cambodia)	Yasothon (Thailand)	Kalasin (Thailand)
Seed and Sowing Cost	392.58	70.17	242.42
Land Preparation Cost	80.979	223.28	223.28
Fertility Input Cost	60.11	384.37	169.45
Irrigation Cost	0	0	0
Cost of Plant Protection Measures	20.853	15.31	15.31
Harvesting and cutting and chopping Cost	441.66	358.85	358.85
Marketing Cost	0	79.74	79.74
Total Cost	**996.18**	**1131.73**	**1089.07**
Total Quantity (kgs)	23500	28125	20681
Price (USD/kg)	0.07	0.06	0.06
Total Revenue	**1738.41**	**1794.25**	**1319.37**
Net Profit	742.23	662.52	230.30
Benefit Cost Ratio	1.74	1.58	1.21
Gross Margin	0.42	0.37	0.17

Harvesting, cutting and chopping along with seed and sowing account for the largest cost items of cassava production in the LMB. The yields of cassava in Kampong Cham (Cambodia), Yasothon and Kalasin (Thailand) are 23.5 tonnes per hectare, 28 tonnes per hectare and 20.6 tonnes per hectare respectively and the net revenue generated per hectare are US$742.23, US$662.52 and US$230.30 respectively. The gross margins of cassava in the three provinces indicate that farmers earn a profit of 42 per cent, 37 per cent and 17 per cent of the invested amount in cassava production in Kampong Cham (Cambodia), Yasothon and Kalasin (Thailand) respectively.

Net Returns and Gross Margin Analysis of Soybean in the LMB (USD/ha)

Items	Battambang (Cambodia)	Percentage
Seed and Sowing Cost	88.33	28.06
Land Preparation Cost	51.53	16.37
Fertility Input Cost	31.89	10.13
Irrigation Cost	0	0
Cost of Plant Protection Measures	20.36	6.47
Harvesting and Threshing Cost	122.68	38.97
Marketing Cost	0	0
Total Cost	**314.80**	**100**
Total Quantity (kgs)	1500	
Price (USD/kg)	0.61	
Total Revenue	**920.12**	
Net Profit	605.32	
Benefit Cost Ratio	2.92	
Gross Margin	0.66	

Soybean is also an important revenue generating crop in the LMB. In soybean production, harvesting and threshing is the main cost item followed by seed and sowing cost. The per hectare yield of soybean is 1.5 tonnes while the net revenue per hectare is US$605.32. The gross margin of soybean indicates a 66 per cent profit on investment in its production.

Net Returns and Gross Margin Analysis of Rain-Fed Rice in the LMB (USD/ha)

Items	Kampong Cham (Cambodia)	Kampong Cham (Cambodia)	Battambang (Cambodia)	Khammouane (Lao PDR)	Dac Lak (Viet Nam)	Yasothon (Thailand)	Kalasin (Thailand)
Seed and Sowing Cost	14.72	18.40	39.50	86.71	209.23	169.46	85.72
Land Preparation Cost	101.83	11.78	80	38.25	189.35	149.52	149.52
Fertility Input Cost	86.86	54.59	153.60	45.90	284.02	426.63	187.40
Irrigation Cost	70.66	0	9.81	76.51	7.10	0	0
Cost of Plant Protection Measures	18.401	18.40	12.02	19.13	28.40	39.87	39.87
Harvesting and Threshing Cost	73.61	61.83	206.41	201.48	142.01	142.01	142.01
Marketing Cost	5.15	16.49	25.76	0	17.04	19.93	27.11
Total Cost	**371.23**	**181.49**	**527.12**	**467.99**	**877.16**	**947.43**	**631.64**
Total Quantity (kgs)	2500	1080	2500	3500	2777	2500	2256
Price (USD/kg)	0.32	0.42	0.22	0.32	0.34	0.57	0.57
Total Revenue	**797.43**	**450.49**	**552.07**	**1123.44**	**946.48**	**1435.40**	**1295.45**
Net Profit	426.20	268.99	24.95	655.44	69.32	487.97	663.81
Benefit Cost Ratio	2.15	2.48	1.05	2.40	1.08	1.51	2.05
Gross Margin	0.53	0.60	0.04	0.58	0.07	0.34	0.51

Net Returns and Gross Margin Analysis of Irrigated Rice in the LMB (USD/ha)

Items	Siem Reap (Cambodia) (Autumn)	Siem Reap (Cambodia) (Spring)	Battambang (Cambodia) (Spring)	Savannakhet (Lao PDR)	Vientiane (Lao PDR)
Seed and Sowing Cost	38.03	38.031	39.50	285.64	79.06
Land Preparation Cost	55.94	55.94	80	306.04	159.39
Fertility Input Cost	94.47	94.47	230.4	520.27	382.55
Irrigation Cost	3.68	3.681	9.81	44.63	63.76
Cost of Plant Protection Measures	29.44	23.55	12.02	0	0
Harvesting and Threshing Cost	68.70	68.70	96	191.27	557.89
Marketing Cost	93.97	93.97	25.76	0	237.82
Total Cost	**384.25**	**378.36**	**493.50**	**1347.87**	**1480.49**
Total Quantity (kgs)	2800	3000	3500	4000	7000
Price (USD/kg)	0.34	0.19	0.32	0.25	0.51
Total Revenue	**961.83**	**588.87**	**1116.41**	**1721.49**	**3570.52**
Net Profit	577.58	210.52	622.90	373.62	2090.02
Benefit Cost Ratio	2.50	1.55	2.26	1.28	2.41
Gross Margin	0.60	0.36	0.56	0.22	0.58

Net Returns and Gross Margin Analysis of Irrigated Rice in the LMB (USD/ha)

Items	Can Tho (Viet Nam) (Winter-Spring)	Can Tho (Viet Nam) (Summer-Autumn)	Can Tho (Viet Nam) (Autumn-Winter)	Tra Vinh (Viet Nam) (Winter-Spring)	Tra Vinh (Viet Nam) (Summer-Autumn)	Tra Vinh (Viet Nam) (Autumn-Winter)
Seed and Sowing Cost	45.44	45.44	45.44	74.79	74.79	74.79
Land Preparation Cost	47.34	47.34	47.33	71.01	71.00	71.00
Fertility Input Cost	224.61	177.28	177.28	307.69	307.69	307.69
Irrigation Cost	66.27	42.60	42.60	14.20	28.40	28.40
Cost of Plant Protection Measures	436.92	507.93	507.93	257.51	257.51	257.51
Harvesting and Threshing Cost	132.54	132.54	132.54	118.34	118.34	118.34
Land Revenue fee	18.93	18.93	18.93	105.19	105.19	105.19
Marketing Cost	0	0	0	0	0	0
Total Cost	**972.07**	**972.07**	**972.07**	**948.74**	**962.94**	**962.94**
Total Quantity (Kgs)	8000	6500	6000	7500	6500	8000
Price (USD/ Kg)	0.35	0.35	0.39	0.29	0.24	0.24
Total Revenue	**2840.24**	**2307.69**	**2328.99**	**2023.67**	**1538.46**	**1893.49**
Net Profit	1868.16	1335.62	1356.92	1074.92	575.51	930.54
Benefit Cost Ratio	2.92	2.37	2.39	2.13	1.60	1.97
Gross Margin	0.66	0.58	0.58	0.53	0.37	0.49

Land preparation and harvesting and threshing are the major cost items in producing rain fed rice in the LMB. The per hectare yield of rain fed rice in the LMB ranges between 1.08 tonnes in Kampong Cham province of Cambodia to 3.5 tonnes in Khammouane province of Lao PDR. The gross margins for rain fed rice indicate the significance of rain fed rice in terms of revenue generation. Rain fed rice generates profits in the range of 4 per cent in Battambang province of Cambodia to 60 per cent in Kampong Cham province.

In the irrigated region of Siem Reap province in Cambodia, rice growers produce two rice crops per year (spring rice and autumn rice) and one irrigated rice crop in Battambang province. Main cost items in producing irrigated rice in Cambodia are fertility inputs and harvesting and threshing costs. Per hectare yields of spring and autumn irrigated rice in Siem Reap are 3 tonnes and 2.8 tonnes respectively while in Battambang province the yields of irrigated rice are 3.5 tonnes per hectare. The net revenues generated per hectare from spring and autumn rice in Siem Reap province are US$210.52 and US$577.58 respectively while in Battambang the net returns to irrigated rice is US$622.90. The gross margins show the percentages of profit earned by investing in the production of irrigated rice.

In Lao PDR, the major cost items in producing irrigated rice are the land preparation, fertility inputs and harvesting and threshing cost. The per hectare yields of rice in Savannakhet and Vientiane provinces of Lao PDR are 3 tonnes and 7 tonnes respectively. Net returns to irrigated rice in Savannakhet and Vientiane provinces are US$373.62 and US$2,090.02 per hectare respectively. The gross margins indicate a 22 per cent profit on investment in Savannakhet province while 58 per cent profit in Vientiane province of Lao PDR.

In Can Tho and Tra Vinh provinces of Viet Nam farmers are producing three rice crops per year (winter-spring rice, summer-autumn rice and autumn-winter rice). The major cost items in both provinces and for all three rice crops (winter-spring rice, summer-autumn rice and autumn-winter rice) are fertility inputs, plant protection measures (including pesticides, herbicides and weedicides etc.) and harvesting and threshing. Per hectare yields of winter-spring rice, summer-autumn rice and autumn-winter rice in Can Tho province are 8 tonnes, 6.5 tonnes and 6 tonnes respectively while in Tra Vinh province the yields of winter-spring rice, summer-autumn rice and autumn-winter rice are 7.5 tonnes, 6.5 tonnes and 8 tonnes respectively. The gross margins indicate significant return/profit on investment in irrigated rice in Can Tho and Tra Vinh provinces of Viet Nam.

Annex-2

Rice Yield in the LMB Countries 1990 to 2012 (MT/ha)

Year	Thailand	Lao PDR	Cambodia	Viet Nam
1990	1.95	2.29	1.35	3.18
1991	2.25	2.2	1.39	3.11
1992	2.17	2.65	1.31	3.33
1993	2.17	2.26	1.3	3.48
1994	2.35	2.58	1.47	3.56
1995	2.41	2.53	1.79	3.69
1996	2.4	2.55	1.81	3.77
1997	2.37	2.76	1.77	3.87
1998	2.45	2.71	1.79	3.95
1999	2.42	2.93	1.94	4.1
2000	2.61	3.06	2.11	4.24
2001	2.77	3.12	2.07	4.28
2002	2.9	3.27	1.91	4.59
2003	2.9	3.14	2.1	4.63
2004	2.85	3.28	1.97	4.85
2005	2.96	3.49	2.48	4.89
2006	2.91	3.58	2.49	4.89
2007	3.01	3.72	2.62	4.98
2008	2.96	3.77	2.74	5.23
2009	2.88	3.84	2.83	5.23
2010	2.93	3.59	2.97	5.34
2011	2.97	3.75	3	5.53
2012	3	3.73	3	5.63

Source: FAOSTAT 2013

Maize Yield in the LMB Countries 1990 to 2012 (MT/ha)

Year	Thailand	Lao PDR	Cambodia	Viet Nam
1990	2.4	1.81	1.95	1.55
1991	2.71	2	1.2	1.5
1992	2.97	1.82	1.25	1.56
1993	2.73	1.75	1.06	1.78
1994	2.93	1.99	1.21	2.14
1995	3.29	1.73	1.22	2.11
1996	3.44	2.09	1.37	2.5
1997	3.19	2.06	1.24	2.49
1998	3.34	2.37	1.22	2.48
1999	3.55	2.36	1.59	2.53
2000	3.67	2.39	2.73	2.74
2001	3.73	2.55	2.76	2.96
2002	3.71	2.76	2.08	3.07
2003	3.85	2.77	3.74	3.43
2004	3.85	3.01	3.32	3.46
2005	3.81	4.33	3.51	3.59
2006	3.93	3.95	3.58	3.73
2007	3.93	4.36	3.69	3.92
2008	4.07	4.83	3.75	3.17
2009	4.18	5.46	4.17	4.01
2010	4.18	4.8	2.34	4.1
2011	4.29	5.17	2.24	4.31
2012	4.45	5.72	2.39	4.29

Source: FAOSTAT 2013

Cassava Yield in the LMB Countries 1990 to 2012 (MT/ha)

Year	Thailand	Lao PDR	Cambodia	Viet Nam
1990	13.91	12.82	5.45	8.86
1991	13.74	13.13	5.09	8.98
1992	14.03	13.1	9.37	9.05
1993	14.05	13.16	5.23	8.81
1994	13.8	13.47	6.5	8.44
1995	13.02	14.03	6.6	7.97
1996	14.16	13.72	5.36	7.5
1997	14.69	10.3	7.68	9.44
1998	14.93	9.21	8.1	7.53
1999	15.49	13.65	16.32	7.99
2000	16.86	9.72	9.6	8.36
2001	17.53	4.09	10.47	12
2002	17.07	7.08	6.32	13.17
2003	19.29	5.84	13.2	14.27
2004	20.28	6.81	16.08	14.98
2005	17.18	7.58	17.86	15.788
2006	21.09	10.33	22.65	16.38
2007	22.92	21.19	20.51	16.53
2008	21.25	17.47	20.42	16.8
2009	22.68	14.71	21.81	16.8
2010	18.83	25.08	20.99	17.26
2011	19.29	23.87	21.31	17.73
2012	18	24.12	21.68	17.69

Source: FAOSTAT 2013

Soybean Yield in the LMB Countries 1990 to 2012 (MT/ha)

Year	Thailand	Lao PDR	Cambodia	Viet Nam
1990	12.99	8.24	14.67	7.87
1991	13.68	9.02	25	7.91
1992	13.99	8.41	25	8.22
1993	13.7	8.21	23.93	8.8
1994	13.25	9.56	10.45	9.43
1995	14.5	8.3	10.44	10.3
1996	14.05	9.08	16.9	10.32
1997	14.31	7.37	17.21	10.62
1998	14.65	7.32	8.94	11.34
1999	14.2	8.6	10.03	11.4
2000	14.53	8.44	8.45	12.03
2001	14.77	9.15	8.59	12.38
2002	14.86	8.39	13.41	12.96
2003	15.4	8.61	12.44	13.27
2004	14.9	8.4	13.09	13.38
2005	15.65	11.64	15.45	14.34
2006	15.6	13.4	15.27	13.9
2007	15.93	13	15.39	14.7
2008	15.99	12.49	14.57	13.93
2009	16.5	15.37	14.24	14.64
2010	16.66	15.8	15.17	15.09
2011	19.63	15.11	16.23	14.69
2012	18	16.37	16	14.52

Source: FAOSTAT 2013

Annex-3

Mean Minimum Temperature, Mean Maximum Temperature and Annual Rainfall in Thailand 1990-2012

Year	Mean Minimum Temperature (Degree Celsius)	Mean Maximum Temperature (Degree Celsius)	Annual Rainfall (mm)
1990	23.3	32.9	1520
1991	23.3	32.9	1440
1992	22.9	32.7	1360
1993	22.8	32.6	1430
1994	23.2	32.6	1710
1995	23.2	32.7	1680
1996	23.1	32.4	1720
1997	23.3	33	1430
1998	23.8	33.6	1490
1999	22.9	32.2	1830
2000	22.7	32.4	1800
2001	23.1	32.7	1690
2002	23.1	32.9	1640
2003	22.9	32.9	1520
2004	22.6	33	1445
2005	23.3	33	1590
2006	23.1	32.85	1680
2007	23	32.8	1640
2008	22.8	32.3	1750
2009	22.9	32.8	1610
2010	23.7	33.5	1650
2011	22.75	32.1	1950
2012	23.6	33.1	1680

Source: Thai Meteorological Department

Annex-4

Assessment of climate change impact on rice yield in Northeast of Thailand

1. Introduction

Rice has long been Thailand's traditional food crop and the country's main export product. Over 80 per cent of the Thai population eats rice as their main meal, with annual per capita consumption totalling 101 kg. Nonetheless, Thailand suffered more than US$1.75 billion in economic losses related to floods, storms, and droughts from 1989-2002, the main share of that (US$1.25 billion) was from crop yield losses (ADB, 2009). Climate change directly affected precipitation and temperature, with rise in temperatures leading to water deficit and floods in the future, changing soil moisture status, and pest and disease incidence (Chinvanno, 2010). Thailand will see drier spells in the middle of the wet season which can damage young plants, and floods at the end of the wet season that will affect harvest. Furthermore, increasing temperature or hotter night temperatures can cause increased spikelet sterility in rice and reduce grain yield (Wassmann and Dobermann, 2007).

The impacts of climate change on rice production in Thailand have been assessed by several research groups. For example, Agarwal (2008) estimated that the yield of Thai rice was expected to decline about 18 per cent in the 2020s because of alterations in temperature and rainfall cycle and through changes in soil quality, pests and diseases as the impacts of climate change. Results from the Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme (MWBP) (2005) indicated that many rice growers in the basin area faced the risk of losing paddy fields from floods and droughts due to climate change. The government of Thailand prepared an action plan on global warming mitigation and raised public awareness on the impacts of climate change (Setsiroot, 2007). In fact, many farmers need to be better informed of the consequence of climate change on their rice production and efficient management of their farms. Individual farmers may adapt in different ways to climate change based on their capability, and individual adaptation schemes would differ from governmental policy that considered a much larger scale.

Analysing the crop production in a watershed needs the information of the water availability which is used in the agriculture in the production processes. These components are challenging to the hydrologist and engineers since they need to evaluate the water availability and design the infrastructure of the agricultural system. As usually the case of natural processes, complex processes in the watershed scale are difficult to understand and simulate. Therefore, modelling approach has been used to predict hydrology processes for the past decade. Hydrology models have the capability of predicting the complex nature of processes as well as the powerful tool to understanding the process. The tools are also effective to assess the effect of change on land use, climate, and management in the future.

Applications of SWAT have expanded worldwide over the past decade, especially in the United States and the European Union on predicting the streamflow. There is little research on the use of SWAT to predict the crop yield especially in the tropical climatic conditions of Thailand. The reason may be scarce data, not only temporal but also spatial scale for modelling in watershed hydrology. However, accurately assessing the hydrological processes in Thailand is a very important task because clearly understanding and predicting them is essential for appropriate watershed management as well as the agricultural system.

2. SWAT for hydrology and crop modelling

SWAT (Soil and Water Assessment Tool) is a river basin scale model developed to quantify the impact of land management practices in the watersheds. SWAT is a continuous time model that operates on a daily time step at the basin scale. The objective of such a model is to predict the long-term impacts in large basins of management and also timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertiliser, and pesticide application rates and timing). It can be used to simulate at the basin scale water and nutrients cycle in landscapes whose dominant land use is agriculture. It can also help in assessing the environmental efficiency of best management practices and alternative management policies. SWAT uses a two-level disagregation scheme; a preliminary sub-basin identification is carried out based on topographic criteria, followed by further discretisation using land use and soil type considerations. Areas with the same soil type and land use form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change.

SWAT is a comprehensive model that requires a diversity of information in order to run. Many of the inputs are used to simulate special features and are specific for each sub-basin. Therefore, for the model purposes, a watershed is divided into a number of sub-watersheds or sub-basins. The use of sub-basins in a simulation is particularly beneficial when different areas of watershed are dominated by one land use or soil which has a certain impact on hydrology. Dividing into sub watersheds allows simulation of different hydrological processes for spatially different groups of land.

The climate to describe the future condition is generated from the general circulation model (GCM) and downscaled using the RCM. In this research PRECIS is used to downscale the GCM. To calibrate the downscaling process, the NCEP/NCAR reanalysis (NNR) was used. Temperature and precipitation is extracted for the study area.

The SWAT model was calibrated for both stream flow and crop production, and using the temperature and precipitation from the downscaling process, the SWAT is run to simulate the hydrological process (stream flow), soil carbon, crop production and water quality. In this paper, only stream flow and crop production was extracted from the model. To assess the impact of climate change on the crop production in the study area, the future simulated crop production is compared with the historical data.

3. SWAT Model description

The public domain model ArcSWAT (version 2009.93.7b) working with the ArcGIS 9.3 interface was selected for this study as it considers spatial variability of soil, land use, climate and also captures human-induced land and water management practices. Soil and Water Assessment Tool (SWAT) is a basin-scale, continuous-time model that operates on a daily time step with the objective of predicting the impact of water/land and agronomic management measures on hydrologic cycles and the accompanying sediment, nutrient and pollutant loadings in un-gauged watersheds (Arnold et al., 1998). The model is physically based, computationally efficient, and capable of continuous simulation over long periods, which can be executed by daily, monthly and yearly step. SWAT comprises sub-modules of weather, hydrology, plant growth, nutrients, pesticides, bacteria, and land management.

The SWAT model was preferred over other models for this study because of its emphasis on water management. Simulation of irrigation water on cropland can be simulated on the basis of five alternative sources: stream reach, reservoir, shallow aquifer, deep aquifer, or water body external to the watershed. The irrigation applications can be simulated for specific dates or with an auto-irrigation routine, which triggers irrigation events according to a water stress threshold.
In addition, SWAT had many successful applications in investigating natural and artificial hydrological cycles under irrigation conditions. SWAT deals with irrigation as a water input, just like it treats precipitation as natural water inputs into a specific hydrological unit.

The model is spatially explicit due to its capability of dividing the Digital Elevation Model (DEM)-delineated watershed into multiple sub watershed, from which a spatially implicit simulation unit – Hydrological Response Unit (HRU) – were further subdivided. HRU consists of a set of homogeneous combination of land use, soil and management features, being determined by users based on either dominant area or user-specified criteria.

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(P_{day} - P_{surf} - ET_a - D_{seep} - Q_{grw} \right) \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where SWt is the final soil water contents at the end of day i; SW0 is the initial soil water content at day i ; t denotes time (day); Pday is the precipitation on day i; Rsurf is the surface runoff on day i; ETa is the actual evapotranspiration on day i ; D seep is the soil percolation on day i ; Qgrw is the return flows on day i . The hydrologic balance is simulated for each HRU, including canopy interception of precipitation, partitioning of precipitation, snowmelt water, and irrigation water between surface runoff and infiltration, redistribution of water within the soil profile, evapotranspiration, lateral sub-surface flow from the soil profile, and return flow from shallow aquifers. SWAT simulates surface runoff volume and peak runoff rates by using daily or sub-daily rainfalls, with the former being calculated by modifying SCS curve number method or Green Ampt infiltration method and the latter being computed by modifying a rational method. A storage routing technique is used to calculate redistribution of water between layers in the soil profile.

Three methods for estimating potential ET are provided: Penman-Monteith, Priestly-Taylor, and Hargreaves. Recharge below the soil profile is partitioned between shallow and deep aquifers. Return flow to the stream system and evapotranspiration from deep-rooted plants can occur from the shallow aquifer. Water that recharges the deep aquifer is assumed lost from the system.

Crop simulation in SWAT is a simplified version of the Erosion-Productivity Impact Calculator (EPIC) plant growth model. The phonological plant development is based on daily accumulation of heat units. The potential biomass is based on w method developed by Montheith, a harvest index is used to calculate yield, and plant growth can be inhabited by temperature, water and fertiliser stress. However, the details of root growth, micronutrient cycling and toxicity responses were not incorporated into SWAT model.

The plant growth in SWAT is controlled using the heat unit concept. Each degree of the daily mean temperature above the base temperature is one heat unit. Therefore, to reach one growth cycle, SAT used the accumulated of the heat unit. The heat unit accumulation for a given day is calculated with the equation:

$$HU = T_{ave} - T_{base} \quad when \quad T_{ave} > T_{base} \ldots\ldots\ldots\ldots\ldots..(2)$$

Where HU = the accumulated heat unit in a given day, Tave is the mean temperature (oC) and Tbase is the plant's base or minimum temperature for growth.

To estimate the biomass production, SWAT model uses the leaf area development, light interception and conversion of intercepted light into biomass assuming a plan species-specific radiation- use efficiency. The amount of daily solar radiation intercepted by the leaf area of the plant is calculating using the Beer's law as follow:

$$H = 0.5H_{day}(1 - \exp(-k_l LAI))\ldots\ldots\ldots\ldots..\ (3)$$

Where H is the amount of intercepted photo synthetically active radiation on a given day (MJ m^{-2}), H_{day} is the incident total solar (MJ m^{-2}), $0.5H_{day}$is the incident photo synthetically active radiation (MJ m^{-2}), $k_l$is the light extinction coefficient, and the LAI is leaf area index.

The potential increase of biomass then calculated as the function of H and radiation uses efficiency (RUE) as the following function:

$$\Delta bio = H.RUE \quad \ldots\ldots\ldots.(4)$$

Where Δbio is the potential increase in total plant biomass on a given day (kg/ha) and RUE is the radiation use efficiency (kg/ha . $MJ/m^2)^{-1}$

Crop yields and/or biomass output can be estimated for various types of crop rotations. Planting, harvesting, nutrient applications, and pesticide applications can be simulated for each cropping system either with user-specified dates or with a heat unit scheduling approach. Nitrogen and phosphorus applications can be simulated in the form of inorganic fertiliser and/or manure inputs. An automatic fertilisation procedure can simulate fertiliser applications, as a function of nitrogen stress.

But over years it has been enabled to account for various biophysical and weather conditions across the globe, not just limited to rain fed agriculture, but irrigation as well. The successful application of SWAT under irrigated cropping systems can be widely found around the world. Santhi et al. (2005) used SWAT to investigate the irrigation water demands and water savings in irrigation projects in Texas, and the results prove that the SWAT model is a useful tool for regional planners and irrigation managers, the successful experiences of which can be applicable in other irrigation systems. Ina most recently published research conducted at San Joaquin Valley, a highly agricultural area relying heavily on irrigation due to the Mediterranean climate, in California, USA (Ficklin et al., 2009),

SWAT was used to investigate the impacts that climatic changes have on hydrological cycles and agricultural water supply and demand. In an earlier research, Rosenberg et al. (2003) used SWAT and HUMUS to examine the potential influences of climatic change on agricultural productivity and irrigation water supply in USA. Both investigations adopted the automatic irrigation setup to uniformly apply irrigation water in irrigation dominated sub-basins, even though this may cause over-prediction of run off in these sun-basins. Numerous studies have shown the application of SWAT in heavily irrigated areas under either humid (Immerzeel et al., 2008; Gosain et al., 2006) or arid climates (Bouraoui et al.,2005). However, in this study, both volume and timing of irrigation were assumed to be uniform within the study sub-basins.

4. Model calibration and validation

A traditional split-sample technique was conducted against observed stream flows of the watershed outlet gauging station. The data from 1998 - 2000 is used for model calibration, data from 2001-2006 for model validation. The calibration process was done by manually adjusting the model parameters within a reasonable range suggested until the predicted monthly stream flows were in acceptable agreement with the observed ones. The model parameters used for calibration consist of two sub-modules that are the base flow module and the surface runoff module.

Two model parameters involving the base flow processes were calibrated. One of the base flow parameter is the threshold water level in shallow aquifer required for return flow to occur (GWQMN). Another base flow parameter is the ground water revap coefficient (GW_REVAP). For the surface runoff processes, three parameters were adjusted in this study. These included the available water capacity of the first soil layer (SOL_AWC), SCS runoff curve number (CN2), and the Manning's "n" for the main channels (CH_N2). All of these parameters were calibrated in order to represent the hydrological processes of the study watershed.

As if it is not feasible to include all parameters in the calibration procedure, sensitivity analysis will be performed for a few locations. Performance evaluation of the model will be assessed based on the Nash–Sutcliffe Efficiency coefficient (E_{NS}) and the correlation coefficient (r) as well as visual comparison of hydrographs. The Ens is determined as:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} [(Q_{obs} -]Q_{sim})^2}{\sum_{i=1}^{n} [(Q_{obs} -] Q_{mean})^2} \quad \ldots\ldots\ldots\ldots (2)$$

where Q_{obs} is the measured monthly discharge (m^3 /s); Q_{sim} is the computed monthly discharge (m^3 /s); Q_{mean} is the average measured discharge (m^3 /s); and n is the number of monthly discharge values.

Coefficient of correlation (R) is one statistical measurement widely used to test the linear relation between two variables. The correlation equation is computed as:

$$R = \frac{\sum_{i=1}^{n} (O_i - O_{mean})(P_i - P_{mean})}{\sqrt{(\sum_{i=1}^{n} (O_i - O_{mean})^2)(\sum_{i=1}^{n} [(P_i - P_{mean})^2)]}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where O is the observed data; P is the model simulated data for the time period entered for evaluation.

Moreover, crop growth parameters for different crops will be adjusted by comparing simulated and measured crop yield in rain fed and irrigated locations.

5. Rice yield under climate change scenarios

SWAT incorporates a simplified version of the Erosion-Productivity Impact Calculator (EPIC) plant growth model. In this model, the phenological plant development is based on daily accumulated heat units, potential biomass is based on a method developed by Monteith (Monteith, 1977), a harvest index is used to calculate yield, and plant growth can be inhibited by temperature, water, nitrogen and phosphorus stress (Neitsch et al., 2001). In this study, the crop productivity is estimated using the value of evapotranspiration and yield data for every catchment area.
To assess the impact of climate change on crop productivity, the future climate projection was applied to the model. As mentioned in the previous section, Future climate projection was generated by Southeast Asia START Regional centre using the ECHAM4 Global Climate Model and downscaled by using PRECIS regional climate model which is based on the existing climate on the past period (1980–1989) and force level of atmospheric CO2 according to IPCC SRES A2 scenario. The future climate scenarios as projected were applied to SWAT model calibrated for the study area to determine the impact of future change on climate on paddy yield. The impacts were considered on the yield changes occurred for the decadal average compared to the yield as obtained for the actual daily weather data.

The meteorological data was provided by the Thai meteorological Department. The rain station closest to the study area was selected for the precipitation data. The daily meteorological data including the precipitation, temperature and evapotranspiration were available for the year 1980 - 2007. The SWAT model was calibrated for the period of 1981–1990 and validated for the period of 1991–2006.

6. Results and Discussion

6.1 SWAT model set up

In this study, the model was setup to simulate the crop productivity based on the change of the future climate. Therefore, the data was design as the input to SWAT model. SWAT requires three basic of data to delineate the sub basin and HRU's such as a digital elevation model (DEM), soil map, and land use/land cover (LULC) data.

Shuttle radar topographic mission (SRTM) DEM (90m resolution) was used in this analysis. A soil map and land use map of Thailand state was collected from the Open source (internet). Daily rainfall data from 15 rain gauge stations, which are spatially spread across the entire catchment, were collected from the multiple sources (internet, report). Further records of meteorological parameters such as daily maximum and minimum temperatures, wind speed, solar radiation and relative humidity were obtained from the SWAT data centre.

The land use data for cropping pattern and crop yield data were collected from the open for the entire Catchment (www.diva-gis.com). As result of calculation 15 of 23 sub-basins and 136 HRUs were delineated in the study area.

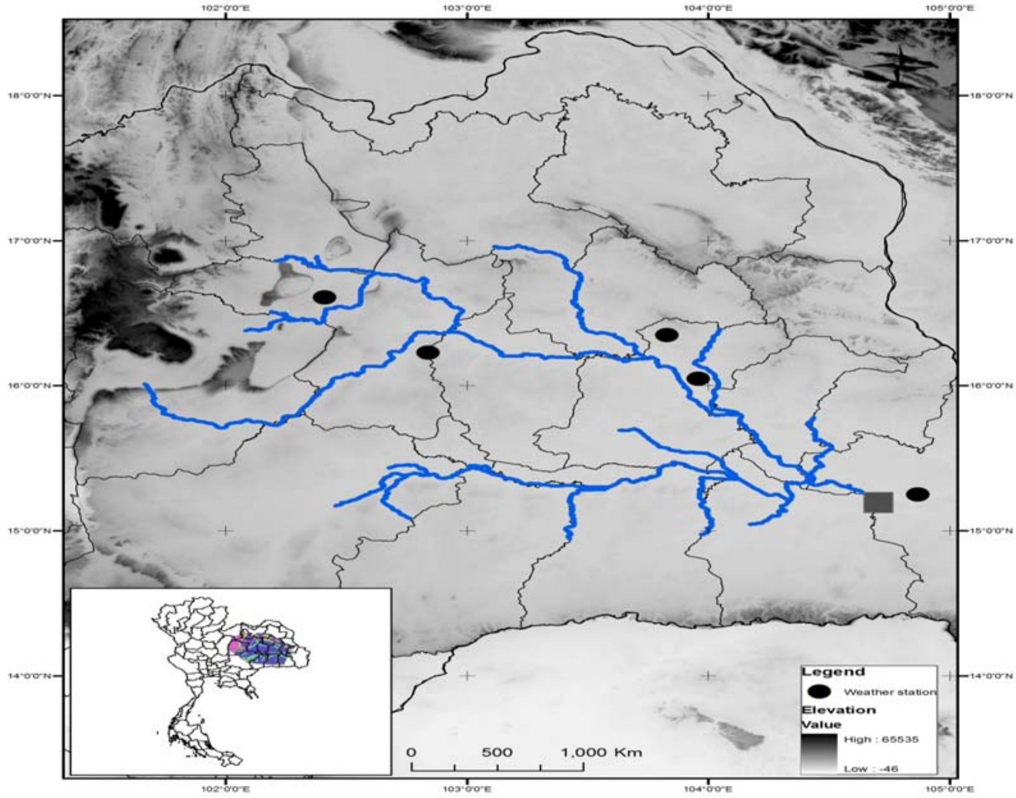

Figure 1. Digital Elevation Model (DEM) and the location of weather station of study area

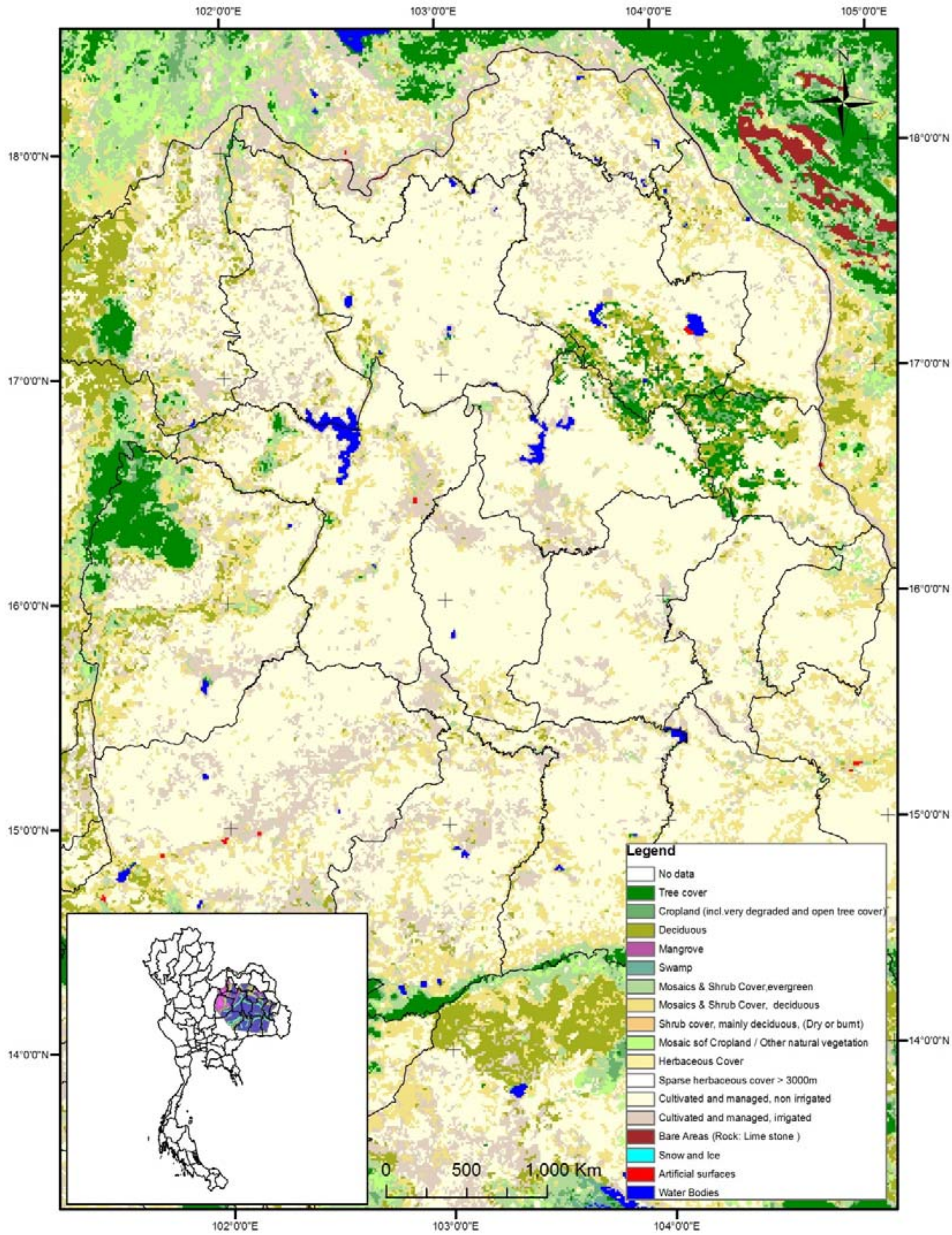

Figure 2. Land use map of the study area

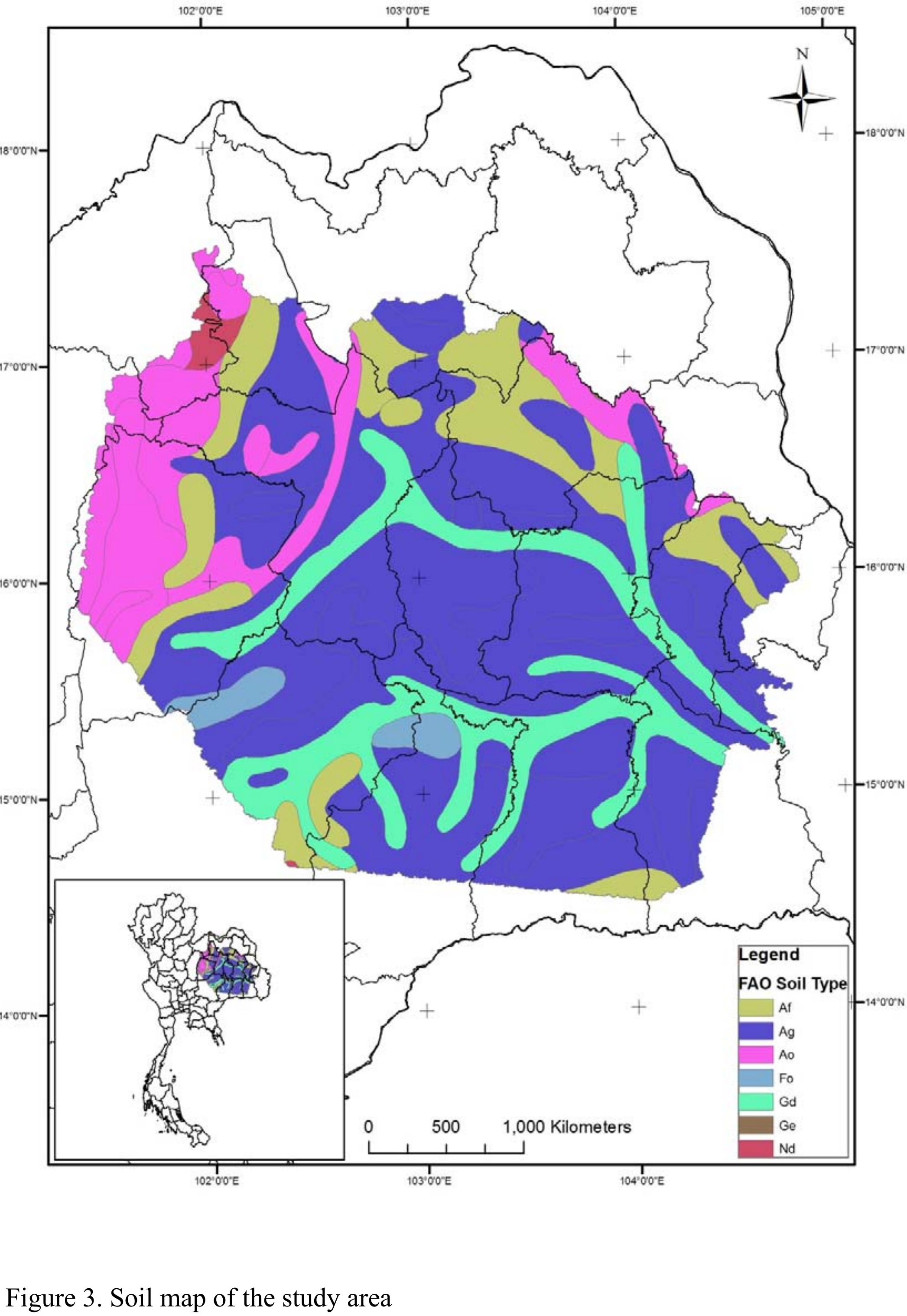

Figure 3. Soil map of the study area

6.2 SWAT calibration and validation

6.2.1 Stream flow

The observed and simulated values of stream flow are shown in Figures 4 and 5 respectively for the calibration and validation periods. The initial and final value of the model parameters for calibration and validation procedures are shown in Table 1, while Table 2 presents the statistic indicators for both calibration and validation.

Table 1. The value of parameters on calibration process

Parameters	Range (unit)	Calibrated
GWQMN	0-100 (mm)	100
GW_REVAP	0.02 -0.20	0.1
SOL_AWC	-	0.5
CN2	± 10%	10%
CH_N2	0.01 -0.3	0.05

Table 2. The statistical value of calibration and validation

Statistical parameters	Calibration		Validation	
	Obs.	Sim.	Obs.	Sim.
Average (m^3/s)	32.6	29.9	36.8	30.9
Peak flow (m^3/s)	220.8	204.5	333.2	302.9
Volume (10^6 m^3)	86.3	87.6	97.38	90.8
R^2	0.805		0.773	
E_{NS} (Nash-Sucliffe)	0.85		0.887	

During the calibration process, the model simulated the stream flow that matched with the observed value with the accuracy about 77%. The simulated flow was substantially underestimated for September–October, but have high accuracy for the other months. The simulated monthly flow of the SWAT model reached the r^2 of 0.78 and E_{ns} = 0.85. The plot of the model prediction and observed data using the scatter plot shows good correspondence.

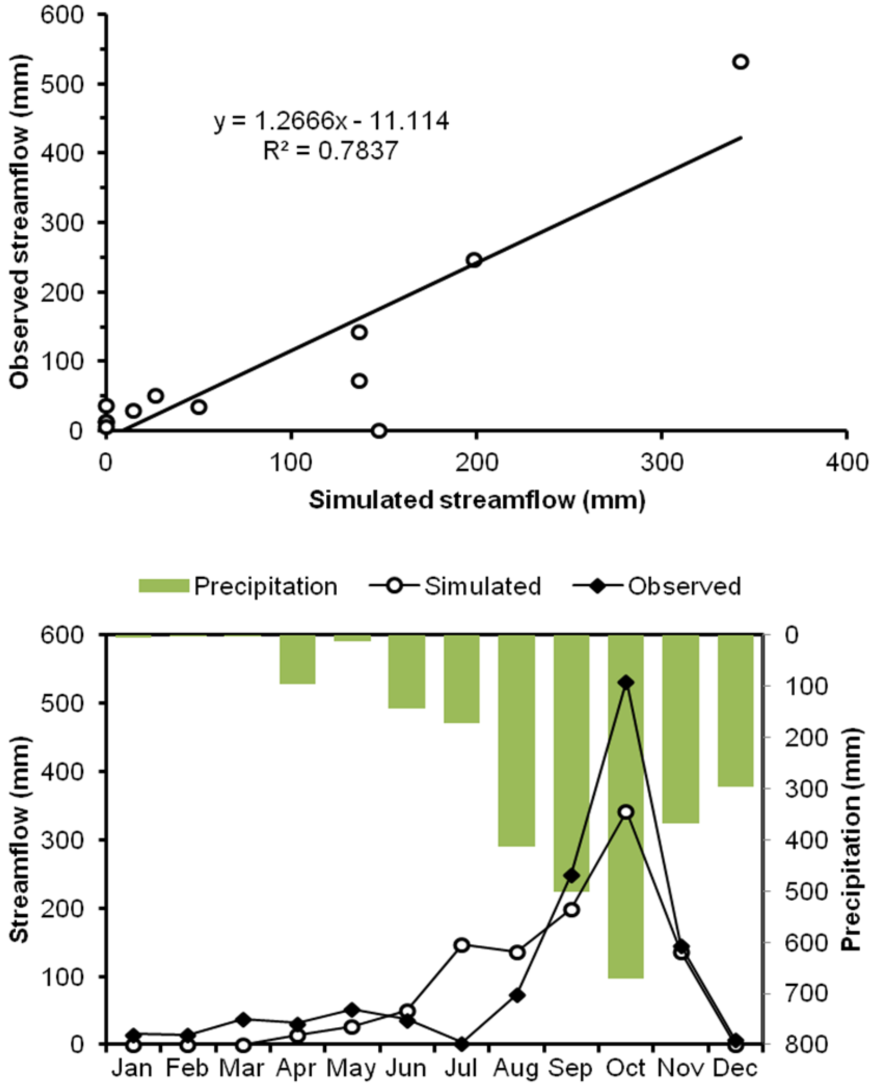

Figure 4. Simulated and Observed streamflow during calibration period

In the validation period, the predicted peak flows and the time to peak matched well with the observed value. Though the peak flow in October was underestimated, the result shows close correspondence. The simulated flow shows good agreement with the observed data with the value of r2 =0.82 and Ens=0.887.

In most cases, monthly stream flows were reasonably predicted by SWAT for the study area during calibration and validation periods. However, stream flows were quite underestimated in the wet month through the period of study.

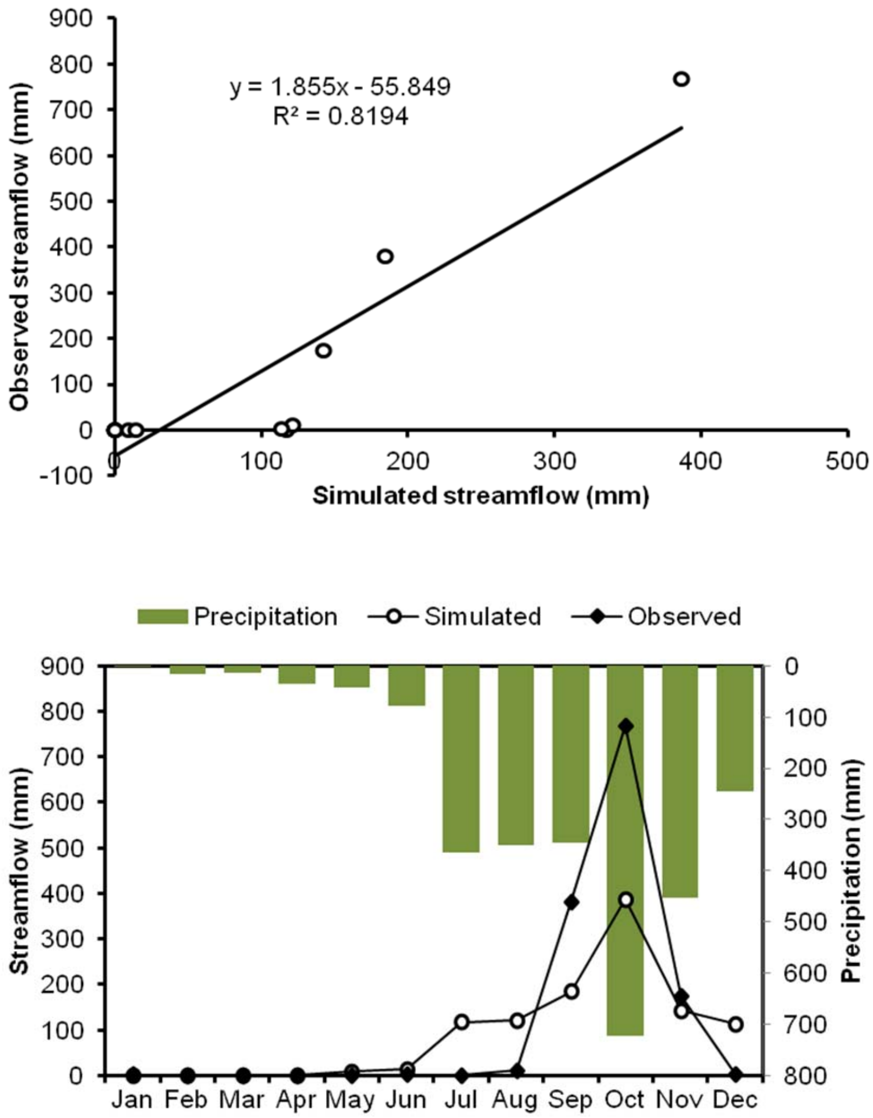

Figure 5. Simulated and Observed stream flow during validation period

6.3 Assessment of future climate on rice yield

6.3.1 Future crop yield under climate change scenario

The future crop is estimated by applying the projected future climate as inputs to the model. To assess the impact of climate change on future crop yield, future land use is assumed to be the same with the current period. The result of future projection is shown in the figure below.

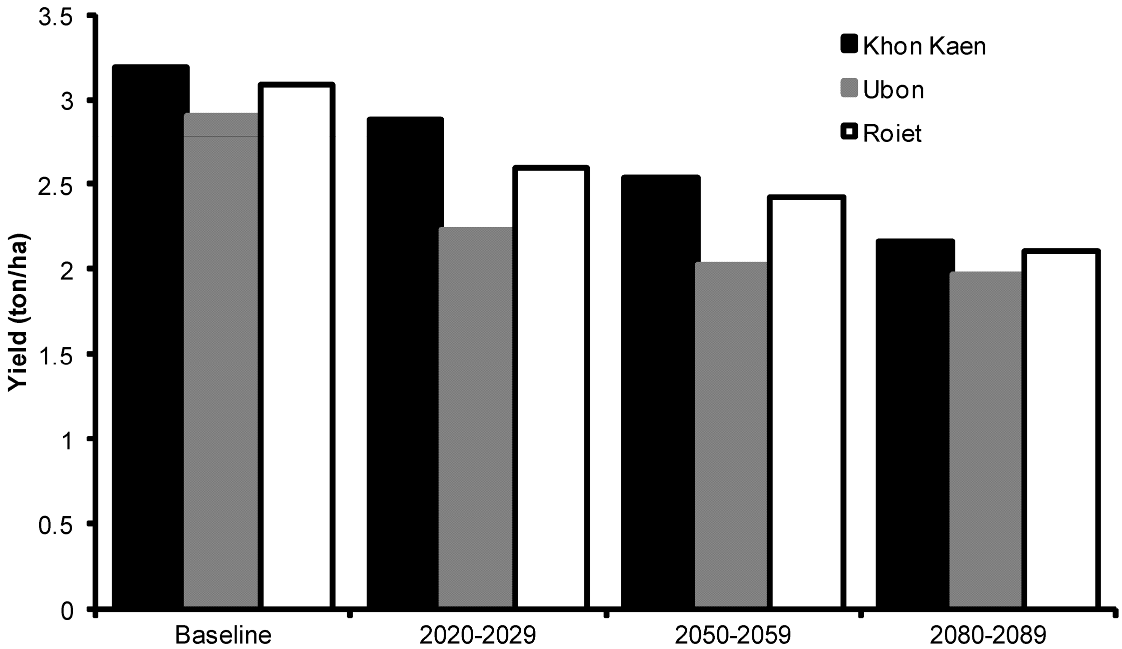

Figure 6. Rice yield in Khon Kaen, Ubon and Roi Et provinces under future climate scenarios

The result shows that the crop production is decreased in the future in all locations. Decreasing of the rice yield is because of the increasing temperature and decreasing precipitation in the study area. Although the increasing temperature will have an effect of increasing yield, the lower precipitation will decrease insitu soil moisture as well decrease the river water to divert for irrigation.

Table 3. Simulated and percentage change of rice yield under future climate change scenarios

	Rice Yield (tonne/ha)			
Location	Baseline	2020-2029	2050-2059	2080-2089
Khon Kaen	3.186	2.876	2.544	2.165
		(-9.73)	(-20.15)	(-32.05)
Ubon	2.908	2.233	2.027	1.975
		(-23.22)	(-30.3)	(-32.1)
Roi Et	3.081	2.597	2.426	2.104
		(-15.7)	(-21.26)	(-31.7)

The simulated rice yield is shown in Table 3. The result shows the reduction of yield in all location about 9 -24% in the period of 2020-2029. The percentages of reduction will increase to the range of 20 -30% and 31 – 32% respectively in the period of 2050 – 2059 and 2080 – 2089. This reduction was caused by the rise in temperature, which would decrease the grain-filling duration. Increasing temperature will reduce the duration between anthesis and maturity in the future, which would affect spikelet sterility and, hence, reduce the final grain yield. The harvest index was also reduced for future periods (Babel et. al., 2011). This condition indicates that, although the total biomass yield remained almost the same, the grain yield will decrease significantly in the future periods.

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Annex-5

ANALYSIS OF CLIMATE CHANGE IMPACTS ON CROP YIELDS IN THE MEKONG RIVER BASIN

1. Introduction

Climate change is already happening and will continue even if global greenhouse gas (GHG) emissions are curtailed (IPCC 2007a). Many studies document the implications of climate change for agriculture and pose a reasonable concern that climate change is a threat to poverty and sustainable development, especially in the developing countries. Despite the climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. The emission of CO_2 is expected to grow about 45–110% by 2030. For the next two decades, a warming of about 0.2°C/decade is projected for a range of Special Report on Emission Scenarios (SRES). Even if the concentration of all GHG's and aerosols has been kept constant at year 2000 levels, a further warming of 0.1 °C/decade is expected (IPCC, 2007b).

Global warming will affect crop yield directly because of alterations in temperature and rainfall cycle and indirectly through changes in soil quality, pests, and diseases. Thus, the yield of food crops (rice-irrigated and rain fed, wheat, maize, and cassava) mainly growing in the Lower Mekong Basin is expected to decline with changing climate. The effect of climate change due to global warming is a major concern to rice production in Asia, which accounts for more than 80% of world production and consumption. At the beginning of the 1990s the annual rice production was 350 million tonnes which reached to 410 million tonnes by the end of the 20th century. After that, it started showing a declining trend with a total production of 395 million tonnes in 2003 (FAO, 2004).

The Mekong River Basin (MRB) comprises six countries: China, Myanmar, Laos, Viet Nam, Thailand, and Cambodia. Agriculture is the main source of livelihood for about 80% of the population in the Mekong Basin. Rice is the most predominant crop in the region with Thailand and Viet Nam being the major rice exporters in the world comprises middle and lower portion of the Mekong Basin. Climate change is an issue of concern as it may cause shift and change in rainy season pattern, which would directly affect agricultural activities of this region. Also most of the countries in the region are developing, so they are more vulnerable to climate change impacts and have very limited resources to cope with the future situations. The knowledge on the subject and know-how to conduct the study on climate change and its impacts is also very limited in most of the Southeast Asian countries. It is important to remember that under rain fed conditions, even a less reliable, but earlier forecast may be more valuable than an accurate but late forecast (Sivakumar, 2006).

Thus, there is a need to predict the future climate regimes, the way it affects the CO_2 concentration, temperature, water cycle, etc., and the rice yield under the changed scenarios. There are still relevant gaps in currently available knowledge regarding some aspects of mitigation of climate change, especially in developing countries. To assess the vulnerability of agriculture to climate change, it is also necessary to consider the role of adaptation. Appropriate adaptation can greatly reduce the magnitude of impacts of climate change. Therefore, it is the need of time to evaluate agro-adaptation measures for the changed scenarios to ensure food security in the region.

1.1 Objectives

The present study focuses on assessment of impacts of future climate change on crop production in middle reaches of MRB. The specific objective is to model and simulate the crop yield under various climate change scenarios.

1.2 Scope of the Study

This simulation study will be conducted using the DSSAT v 4.5 crop growth simulation model at the regional level in selected provinces of Northeast Thailand, which is a part of the Mekong Basin. The scope of the study includes the following:

- Identification of the common rice varieties in Northeast Thailand and analysis of their characteristics
- Assessment of yield pattern of the identified rice varieties in the study area
- Collection of data on soil, weather and crop characteristics for the selected region of Northeast Thailand
- Calibration of DSSAT crop simulation model using the experimental data collected from secondary sources for the selected rice varieties
- Downscaling of future climate data for the climate stations located in the study region using statistical downscaling models
- Analysis of the future climate scenarios and determination of their effects on rice yield using the calibrated CERES-Rice model

2. Study Area and Data

2.1 Study Area

The Mekong Basin comprises of six countries having an area of 795,000 km^2. The Lower Mekong River Basin comprises of Cambodia, Lao PDR, Thailand and Viet Nam, is the home to approximately 60 million people. The Mekong River in Thailand passes through the whole of Northeast Thailand and its basin there comprises almost 19 provinces located in the Northeast (Figure 1). These provinces lie between latitude 14.5 to 17.5°N and longitude 102.12 to 104.9°E. It covers almost one-third area of Thailand, which is the most productive region for rice. Rice production in Northeast Thailand relies mainly on rainfall; irrigation is limited to about 20% of the region.

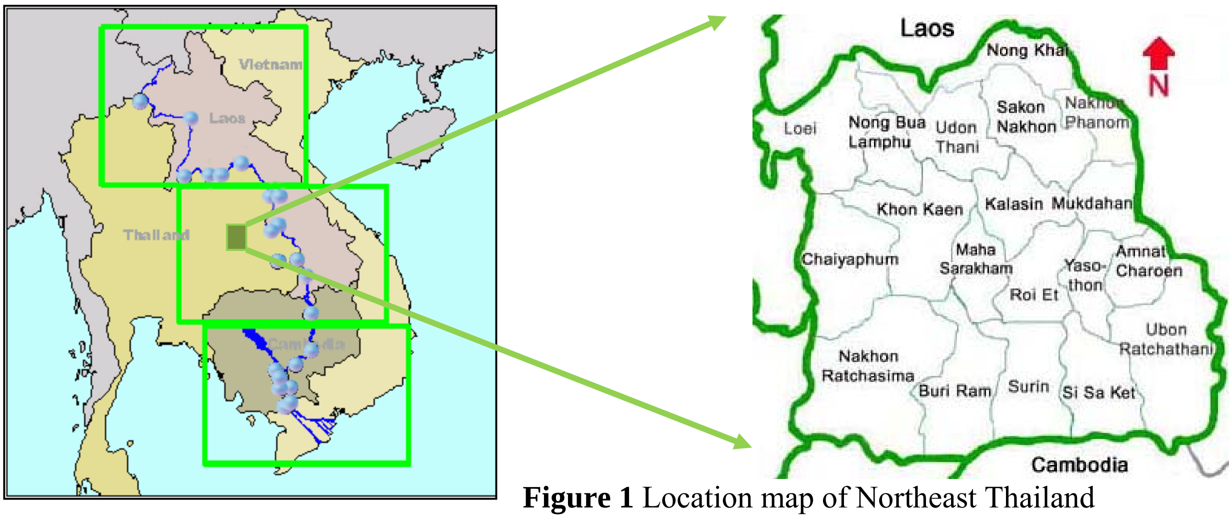


Figure 1 Location map of Northeast Thailand

Northeast Thailand, also known as Isan, is a water-challenged region of Thailand with a large number of droughts which are likely to increase in frequency as well as in intensity with climate change. About 80% of the people in the Great Mekong Basin have agriculture as their source of livelihood. Rice is the most predominant crop in this region. Northeast Thailand has about 9.3 million hectares of agricultural land, of which approximately 7.9 million hectares are used for rain fed farming. Up to 75% of this land is devoted to rice, but the planted area varies considerably from year to year, mainly because of variable water availability. As a result of the poor physical endowment of the region, for example, generally poor soils, highly uneven distribution of rainfall, and very limited irrigation facilities, average rice yields in Northeast Thailand (1.9 t ha^{-1}) are the lowest in the country (average of 2.5 t ha^{-1}) (Haefele et al., 2006).

The three Provinces—Khon Kaen, Roi Et, and Ubon Ratchathani—in Northeast Thailand, were selected for this study. The Provinces were selected on the basis that they represent the different regions in Northeast Thailand as shown in Figure 2. The two major Rivers namely the Chi and the Mun Rivers of Northeast Thailand, which are also tributaries of the Mekong River, flow through these provinces. Thus they are very important in terms of agricultural development in the Northeast region of Thailand.

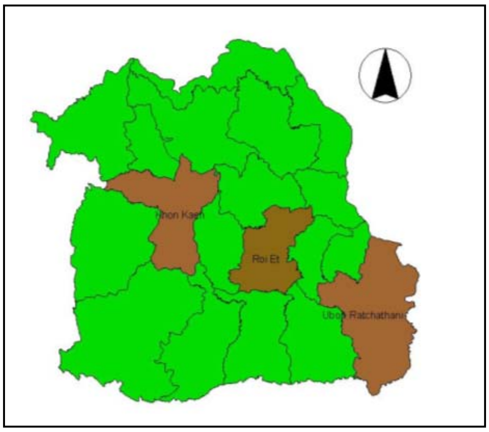


Figure 2 Location of three study Provinces in Northeast Thailand

2.2 Data

2.2.1 Rice Cultivation in Northeast Thailand

- Rice is sown mainly during June and July in which more than 80% of the sowing is done and the main harvesting season is November and December
- 70% of the cultivation is of transplanted rice along with other cultivation practices as broadcasting and sowing pre-germinated seeds
- The major rice varieties grown in the Northeast of Thailand are KDML105, RD6, RD15, Klong Luang 1, Pathumtani, Suphanburi, Pitsanulok, and Chainat.
- The major varieties grown by the farmers are KDML105 and RD6 of which more than 80% of the total production in the region consists

The total production of the rice and production of major varieties during the period of 2001 to 2005 are as shown in Figure 3.

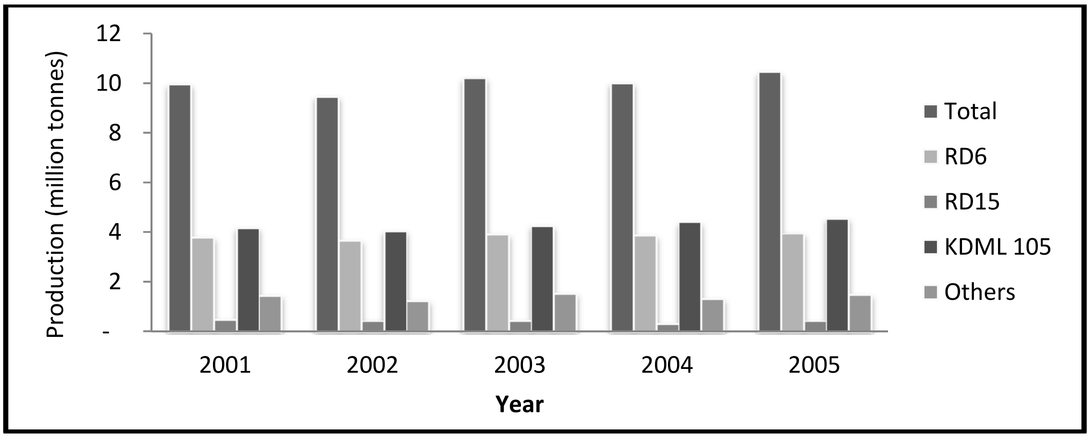


Figure 3: Major rice varieties according to production in Northeast Thailand

There was an increase of almost 157,000ha of area under rice cultivation in 2006 as compared to 1989. Also during the period, the average yield of rice in the region increased from 1.57 tonnes/ha to 2.09 tonnes/ha. The trend of change in area under cultivation and yield were as shown in Figure 4. As a result, the total rice production in the region increased from 7 million tonnes in 1989 to 10 million tonnes in 2003.

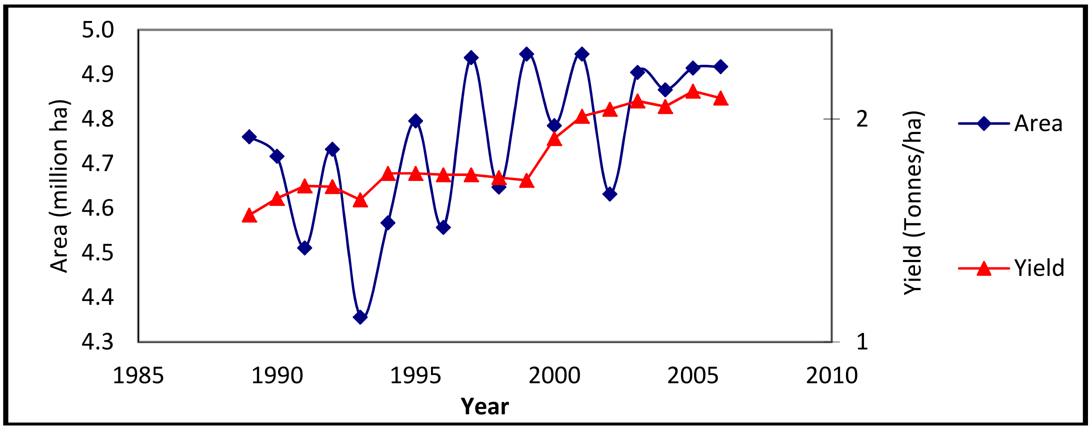


Figure 4 Area and yield of rice crop in Northeast Thailand.

The major area under rice cultivation is still rain fed and there is no significant increase in area under irrigation in the region. The main constraint in the increase of irrigation facility is the lack of rainfall. Figure 5 shows that the increase in rain fed area under rice cultivation was the same as increase in total area during the given period.

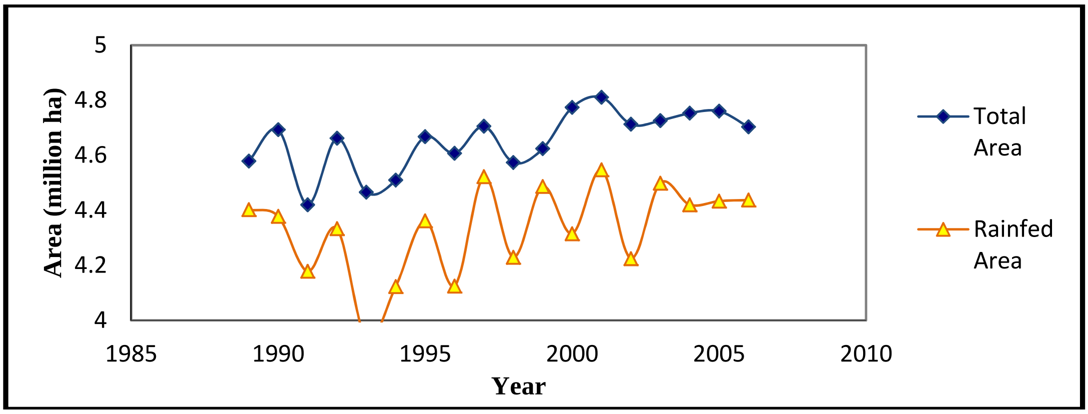


Figure 5 Total area and rain fed area under rice cultivation in Northeast Thailand

2.2.2 Experimental Data for Rice Crop

Rice research centres located in Northeast Thailand used to conduct many experiments to improve the crop production and productivity in the region. The details of some of the field experiments conducted by the Rice Research Centers were collected and used for DSSAT model calibration and validation. These experiments were conducted at Research Centers located in Roi Et, Khon Kaen, and Ubon Ratchathani Provinces. The experiments in Roi Et Province were carried out in 2004 at farmer's field using the cultivars KDML105 and RD6, and in 1997 at the Rice Research Centers in Khon Kaen and Ubon Ratchathani for cultivar KDML105. These experiments were conducted to test the effect of planting dates, fertiliser application, rain fed versus irrigation watering, management practices, etc., on yield and yield components of rice. The various management details, treatments, and yield components of the experiments are given further.

Experiment Set I

The experiment in Roi Et was conducted to test the appropriate amount of fertilisers to maximise the yield of rice. The experimental treatments include application of different rates of N under the similar management conditions. Different N rates were applied in experimental plots according to farmers' practice, no fertiliser, and as recommended by the Rice Research Center. The details of the experiment are provided in Tables 1 and 2. The initial preparation includes soil ploughing twice and harrowing once before transplanting. The method of plantation used was transplantation in all experiments. The plots of 8 m^2 were used for the experiments.

Table 1 Crop characteristics and other data from the experiment conducted for the cultivar KDML105 at Roi Et

No.	**Agriculture Practice**	**Date/Description**
1	Seeding	20th June 2004
2	Soil Preparation:	
	1st plow	15th July 2004
	2nd plow	29th July 2004
	Harrow	29th July 2004
3	Transplant : Date	29th July 2004
	Age	39 days
4	Plants (per 8 m^2)	146
5	Flowering Date	21st Oct 2004 (04291)
6	Harvest: Area	8 m^2
	Date	16th Nov 2004 (04321) ie.149 DAS or 110 DAT
7	Treatments	
	(i) Farmers Practice	Fertiliser type 16-16-8 @ 175 kg/ha on 27th July 2004 and @ 94 kg/ha on 19th October 2004
	(ii) No Fertiliser	
Yield Components	**Treatment 1**	**Treatment 2**
Maturity Day	16th Nov 2004 i.e. 149 DAS	16th Nov 2004 i.e. 149 DAS
Straw Weight	2422 kg/ha	1910 kg/ha
Grain Yield	1810 kg/ha	1220 kg/ha
Harvest Index	0.42	0.40

Source: Rice Research Center, Roi Et (2007)

Table 2 Crop characteristics and other data from the experiment conducted for the cultivar RD6 at Roi Et

No.	**Agriculture Practice**	**Date/Description**
1	Seeding	23rd May 2004
2	Soil Preparation:	
	1st plow	20th May 2004
	2nd plow	29th June 2004
	Harrow	29th June 2004
3	Transplant : Date	30th June 2004
	Age	38 days

4	Plants (per 8 m^2)	108	
5	Flowering Date	21th Oct 2004 (04291)	
6	Harvest: Area	8 m^2	
	Date	22nd Nov 2004 (04321) i.e.183 DAS and 145 DAT	
7	Treatments		
	(i) Farmers Practice	Fertiliser type 16-16-8 @ 376 kg/ha on 15th	
	(ii) No Fertiliser	July 2004 i.e. 15 DAT	
	(iii) Recommended	Fertiliser type 16-16-8 @ 156 kg/ha on 1st July 2004 i.e. 1 DAT	
Yield Components	**Treatment 1**	**Treatment 2**	**Treatment 3**
Maturity Day	22nd Nov 2004 i.e.183 DAS	22nd Nov 2004 i.e.183 DAS	22nd Nov 2004 i.e.183 DAS
Grain Yield	3280 kg/ha	2890 kg/ha	3430 kg/ha
seeds/m^2	11554	10231	12040
Harvest Index	0.463	0.507	0.513

Source: Rice Research Center, Roi Et (2007)

Experiment Set II

The experiments to test the impact of drought stresses on rice yield were conducted during the period of 1996–1998 at Chum Phae Rice Research Center, located in Khon Kaen and Ubon Rice Research Center, located in Ubon Ratchathani. The yield of rice cultivar KDML105 under drought stresses was analysed with different sowing dates. The specific details for different experiments are given in Tables 3–5.

Chum Phae Rice Research Center

Plot details: area = 4.2 m^2, rows = 7, row spacing = 20cm, row length = 3m, 15 hills per row spaced 20 cm.

Table 3 Crop characteristics and other data from the experiment conducted at Chum Phae

No.	Agriculture Practice	Date/Description
1	Seeding	8th August 1997
2	Transplant : Date	28th August 1997
	Age	20 days
3	Plants (per m^2)	25
4	Flowering Date	1st Nov 1997 (85 DAS)
5	Harvest: Area	1.42 m^2
	Date	27th Nov 1997 (111 DAS)
6	Treatments	
	Rainfed	

Yield Components	
Plant Height	104 cm
Yield	2940 kg/ha
Harvest Index	0.45
Straw Weight	3595 kg/ha

Source: Chum Phae Rice Research Center, Khon Kaen (2007)

Ubon Rice Research Center
Plot Details: Area 4.08m^2, 6 rows 17 cm apart, row length 3.6m, 18 hills per row spaced 20 cm apart
Fertiliser: mixed chemical; N-19kg/ha; P-38 kg/ha; K-38kg/ha 31 DAS.
N-19kg/ha 67 DAS

Table 4: Crop characteristics and other data from the experiment conducted at Ubon

No.	Agriculture Practice	Date/Description
1	Seeding	8th August 1997
2	Transplant : Date	5th Sept 1997
	Age	28 days
3	Plants (per m^2)	27
4	Flowering Date	3rd Nov 1997 (85 DAS)
5	Treatments	
	Rainfed	Light Irrigation during flowering
	Yield Components	
	Yield	3360 kg/ha
	Harvest Index	0.40
	Straw Weight	4800 kg/ha
	1000 grains weight	25 grams

Source: Ubon Rice Research Center, Ubon Ratchathani (2007)

Table 5 Crop characteristics and other data collected from the experiment conducted at Ubon for Rainfed conditions with late seeding dates

No.	Agriculture Practice	Date/Description
1	Seeding	28th August 1997
2	Transplant : Date	26th Sept 1997
	Age	28 days
3	Plants (per m^2)	27
4	Flowering Date	18th Nov 1997 (80 DAS)
5	Treatments	
	Rainfed	Light Irrigation during flowering

Yield Components	
Yield	2720 kg/ha
Harvest Index	0.38
Straw Weight	4450 kg/ha
1000 grains weight	25 grams

Source: Ubon Rice Research Center, Ubon Ratchathani (2007)

2.2.3 Crop Genetic Coefficients

The genetic coefficients for the selected rice cultivars grown in north and Northeast Thailand were derived by Buddhaboon, et al. (2004) and are as presented in Table 6.

Table 6 Genetic coefficients of rice cultivars, KDML105 and RD6

Rice Cultivar	Genetic Coefficients							
	P1	P5	P2R	P2O	G1	G2	G3	G4
KDML105	502.3	386.5	1233.0	12.7	45.7	0.027	1	0.95
RD6	550.3	386.5	1243.0	12.8	48.7	0.028	1	0.95

Source: Buddhaboon et al. (2004)

2.2.4 Soil Data

The information about physical and chemical properties of the soil series in Northeast Thailand was collected from the Land Development Department, Bangkok, Thailand. There are almost 44 established soil types in Northeast Thailand. The major soil types used for rice cultivation are Roi Et, Ubon, Udon, Renu, and Si Thon. The data collected for soil types includes colour, slope, runoff potential, drainage type along with layered classification of soil texture, pH, phosphorous, potassium, carbon, nitrogen, and cation exchange capacity. The properties of soil type in three study sites are given in Tables 7–9.

Roi Et series

Colour: Brown
Slope: 0-1%
Runoff: Slow
Drainage: somewhat poorly drained
Land use: Transplanted rice

Table 7 Physical and chemical properties for the Roi Et Soil Series

Soil Depth (cm)	USDA grading			pH		P, $mgkg^{-1}$ Bray 2	K, $mgkg^{-1}$ NH4OAc	C %	N %	CEC $cmolkg^{-1}$
	sand	silt	clay	1:1 Water	1:1 KCl					
0-19	67.9	11.6	20.5	5.2	4.6	16.1	66	0.33	0.03	12.2
19-38	62.8	16.2	21.0	5.5	4.5	2.0	51	0.06	0.01	9.5
38-50	65.4	9.6	25.0	5.5	4.4	1.2	45	0.03	0.01	11.6
50-74	63.2	13.3	23.0	5.0	4.0	1.2	39	0.04	0.01	14.0
74-93	65.3	14.2	20.5	5.1	4.0	1.0	27	0.05	0.01	15.1

Source: Land Development Department, Thailand (2003)

Ubon series
Colour: Brown
Slope: 0-1%
Runoff: Slow
Drainage: moderately well drained
Land use: Paddy Field

Table 8 Physical and Chemical Properties for the Ubon Soil Series

Soil Depth (cm)	USDA grading			pH		P, $mgkg^{-1}$ Bray 2	K, $mgkg^{-1}$ NH4OAc	C %	N %	CEC $cmolkg^{-1}$
	sand	silt	clay	1:1 Water	1:1 KCl					
0-18	81.0	18.0	1.0	4.1	3.8	1.6	11	0.34	0	140
18-56	86.6	10.4	3.0	4.8	4.1	1.1	11	0.06	0	10
56-94	81.9	17.6	0.5	6.1	5.4	0.6	12	0.02	0	60
94-120	79.9	16.1	4.0	5.6	4.0	1.2	10	0.04	0	25
120-164	76.8	16.6	6.6	5.3	3.9	1.8	7	0.06	0	15.2
164-200	65.4	18.9	15.7	5.6	4.1	1.0	14	0.14	0	10.8

Source: Land Development Department, Thailand (2003)

Renu series
Colour: Yellow
Slope: 0-1%
Runoff: Slow
Drainage: somewhat poorly drained
Land use: Transplanted rice

Table 9 Physical and chemical properties for the Renu Soil Series

Soil Depth (cm)	USDA grading sand	silt	clay	pH 1:1 Water	1:1 KCl	P, $mgkg^{-1}$ Bray 2	K, $mgkg^{-1}$ NH4OAc	C %	N %	CEC $cmolkg^{-1}$
0-11	45.3	52.2	2.5	4.7	3.8	1.3	14	0.38	0	96.0
11-24	41.9	49.4	8.7	4.7	3.8	1.1	17	0.14	0	32.2
24-36	36.9	47.2	15.9	5.0	3.7	1.6	26	0.19	0	40.3
36-79	40.4	40.2	19.4	4.8	3.6	1.8	30	0.13	0	29.9
79-110	33.5	32.6	33.9	5.2	3.5	1.6	59	0.09	0	33.6
110-140	34.9	40.8	24.3	5.4	3.5	1.9	31	0.07	0	35.4

Source: Land Development Department, Thailand (2003)

2.2.5 Weather Data

The weather data was collected from the Thai Meteorological Department for the weather stations in Khon Kaen, Roi Et, and Ubon Ratchathani. Data for the nearest station from the experimental plot was used for this study. The daily weather data including rainfall, maximum and minimum temperatures, sunshine hours, wind speed, and evaporation were collected for the period of 1980–2007. The location of weather and rainfall stations is given in Table 10.

Table 10 Location of weather and rainfall stations

Province	Weather Station		Rainfall Station	
	Longitude	Latitude	Longitude	Latitude
Khon Kaen	102.84°E	16.23°N	102.41°E	16.61°N
Roi Et	103.69°E	16.05°N	103.83°E	16.35°N
Ubon Ratchathani	104.87°E	15.25°N	104.87°E	15.25°N

Source: Thai Meteorological Department, Khon Kaen, Roi Et, and Ubon Ratchathani (2007)

2.2.6 Future Climate Data

The future climate data for this study was used from the Hadley Centre Coupled Model, version 3 (HadCM3) for two IPCC SRES scenarios B1 and A2. The GCM data is available from the IPCC data distribution centre (IPCC-DDC) website. The emission scenarios were selected based on their assumptions of future projections. The A2 scenario, which is one of the most pessimistic scenarios, describes the future world as very heterogeneous with regionally oriented economic development. Thus A2 scenario assumes large increase in greenhouse gas emissions and thus significant negative impacts on climate. The B1 scenario is the most optimistic scenario which assumes a sustainable development path to be followed in the future. As per B1 scenario, the emphasis in future is on global solutions to economic, social, and environmental sustainability, without additional damages to the climate. The low resolution climate data from the GCMs was downscaled for the study region using statistical downscaling model LARS-WG. The data for GCM HadCM3 for two scenarios B1 and A2 are available in model LARS-WG 5 database. The data for the grids under which the study Provinces exist were used in this study.

3 Methodology

3.1 Development of Crop Growth Model

A large number of crop growth models are available to simulate the rice production. These models include ORYZA, CERES-Rice, SIMRIW, ORYZA2000, INFOCROP, AQUACROP, etc. Each model has its specific methods, underlying assumptions, and complexity. Various scientific studies conducted in Thailand recommended the use of ORYZA and CERES-Rice (Kumar et al., 2013). The CERES-Rice model, which is part of DSSAT, is considered to be more suitable for climate change impact analysis (Babel et al., 2011) as it provides options to analyse the impacts of CO2 enhancements, temperature change, and precipitation change on yield in future periods.

Thus the CERES-Rice model (Singh et al. 1993, Ritchie et al. 1998) available with the DSSAT Version 4.5 (Hoogenboom et al. 2003) developed by the International Consortium for Agricultural Systems Application, University of Hawaii, USA, was used in this study. The DSSAT model can predict the plants growth and yield and is based on the understanding of plants, weather, soil, and management interaction. Yield-limiting factors like nutrient stresses (N and P), water stress, etc., are considered by the model. The DSSAT includes a suite of tools, main tools includes: XBuild to create and modify experimental files, Weatherman for weather data, SBuild for soil database and GBuild for graphing of outputs, and are available for data management and analysis (Hoogenboom et al. 2003). It is a process-based, management-oriented model that can simulate the growth and development of rice as affected by varying levels of water and nitrogen. The model can identify gaps between potential and on-station and on-farm yields.

Data required to calibrate a crop simulation model are:

- Daily weather data: maximum and minimum temperatures, relative humidity, rainfall, solar radiations
- Crop data: experimental data on time series crop biomass, leaf area index at various crop growth stages
- Soil data: physical properties; soil texture, and structure. Chemical properties; nitrogen content, phosphorous content, potassium content, total volatile solids, carbon and ash content.
- Crop genetic coefficients

In CERES-Rice the genetic coefficients, as defined by Ritchie et al. (1998), are used as model inputs to describe crop phenology in response to temperature and photoperiod. The genetic coefficients used for the growth and development of rice varieties are:

- P1: basic vegetative phase, the time period expressed as growing degree days (GDD) in degrees Celsius above a base temperature of 9°C
- P2O: critical photoperiod or the longest day length in hours at which the development occurs at a maximum rate
- P2R: photoperiod sensitivity coefficient, the extent to which the phasic development leading to panicle initiation is delayed
- P5: time period in GDD from the beginning of grain filling to physiological maturity with a base temperature of 9°C

- G1: potential spikelet number per panicle
- G2: single grain weight
- G3: tillering coefficients relative to IR64 cultivars
- G4: temperature tolerance coefficient.

Steps to develop a model can be summarized as

- Data collection and preparation
- Model setup
- Calibration
- Verification
- Application

The data obtained from the field experiments conducted by the Rice Research Center in Ubon Ratchathani, Roi Et, and Khon Kaen for crop growth characteristics, i.e. flowering day, maturity day, grain yield, and harvest index, were compared with the simulated results for the model calibration and validation. The model was further evaluated by using the observed and simulated weather data for 1981–2000 as an input to the calibrated model and comparing the simulated yields at the 3 locations with the observed yields.

3.2 Analysis of impacts of future climate change

GCMs are an important tool to produce the virtual estimate of climate change in the future but their information remains relatively coarse in resolution for impact studies (Chiew et al., 2010). Two fundamental approaches exist to bridge the gap between large and local scale climate data; the first is a dynamical approach where a higher resolution climate model (RCM) is embedded within a GCM. The main limitation of RCMs is the high computational cost and their coarse resolution output for impact analysis on watersheds or agriculture sector (Chen et al., 2011). The second approach is to use statistical methods to establish empirical relationships between GCM output, climate variables, and local climate (Fowler et al., 2007). Statistical downscaling (SD), provides an easy to apply and much rapid method for climate change impact assessment studies and thus more widely adopted (Chen et al., 2011; Chiew et al., 2010). SD techniques can be grouped into three categories: weather typing method, stochastic weather generators, and regression methods.

In this study we use statistical downscaling model LARS-WG (Semenov & Barrow, 1997) to downscale the low resolution climate data obtained from the GCMs. LARS-WG can generate synthetic daily datasets of rainfall, minimum and maximum temperatures, and solar radiation based on the observed weather, generally 20 or 30 years of daily climate data are used in order to capture real climate variability and seasonality. The GCM data have grid size with low resolution of 100s of km. For this study the GCM grids were identified for the study sites based on the location of the weather station in each of the Province. Then the statistical model was used to downscale the low resolution GCM data to the point scale using the baseline period (1981-2000) obtained for the individual climate station. Based on the relative monthly changes in mean daily rainfall, wet and dry series duration, temperature and temperature variability between current and future periods predicted by GCM, local station climate variables are adjusted proportionately to represent climate change. Three steps are performed in LARS-WG model to develop the synthetic weather data:

Site analysis
To perform a preliminary analysis of the observed dataset and to exclude certain possible errors which can be present in the observed data site analysis is done. During site analysis model calibration is also done for LARS-WG. Model calibration here consists of calculating the relevant statistical parameters for each meteorological variable from the observed historical data. These parameters are then used to stochastically generate realistic climate data corresponding to the present or future climate scenario, respectively. The mean of observed daily rainfall as well as daily maximum and minimum temperatures are used to extract the statistical parameters of the current climate. For rainfall, these parameters consist of monthly histogram intervals and frequency of events in each interval for dry and wet spell lengths, as well as rainfall amounts. Temperature is modelled by using Fourier series which can be constructed with parameters such as mean value, amplitude of the sine and cosine curves and phase angle. Both maximum and minimum temperatures are modelled more accurately by considering wet and dry days separately; therefore, the temperature parameters for wet and dry days are derived separately. The weather generator also uses parameters corresponding to average autocorrelation values for minimum and maximum temperature derived from observed weather data.
Q – test
After the observed weather data are analysed, the derived statistical parameters are used to generate synthetic weather data representing the current climate. To get a representative statistics of the synthetic data, maximum 300–year data can be generated for each climate variable considered. When the site parameters are calculated, Q-test is performed to analyse the calibration results. A test file is created with results of statistical tests, which assess the ability of LARS-WG to reproduce variety of weather statistics accurately. The performance of the model to downscale the climate for the three stations located in the study Provinces is presented in Section 4.2.

Creating climate change scenarios
To incorporate changes in climate variability and generate scenarios, the relative change between the GCM baseline period and the GCM future scenario are calculated. Parameters calculated here are: relative change in wet and dry season's length; relative change in mean temperature, standard deviation for each month; and mean changes in rainfall amount, mean temperature, and solar radiation for each month. The changes in mean temperature are additive changes, and changes in monthly rainfall, length of the wet and dry spells and temperature standard deviation are multiplicative. These parameters are then applied to the generated synthetic weather data for baseline period which will represent the future climate for the station as per the GCM and scenario applied.

The predicted future climate data were applied to the calibrated CERES-Rice model for the study sites to determine the impacts on rice yield during the 3 future periods. The impacts were then determined by computing the changes in the yield averaged for the future periods with respect to the yield as obtained for the simulated daily weather data for the baseline period.

4. Results and Discussion

4.1 Model development

For development of the DSSAT model, the experimental data collected from research stations along with soil data, daily weather data, and rice genetic coefficients was used as the input parameter. The soil at the site had very poor nitrogen content, which led to nitrogen stress during the main growth stages. The parameter used for the model calibration was initial crop residue in the field. The yield components which were considered during the calibration of model were flowering day, harvest index, and grain yield. The simulated values from the model were compared with the observed values. The percentage error within the range of 10% was considered as satisfactory for the model calibration. The comparisons of observed and simulated values at various sites are discussed below.

Roi Et for Cultivar RD6

The experiment with three different rates of nitrogen fertiliser was conducted in 2004 at Roi Et. The first, mentioned as RE1, uses N fertiliser @ 376 kg/ha, the second, RE2, was without any fertiliser while the last, RE3, uses N fertiliser @ 156 kg/ha. The model simulated the yield in all three cases satisfactorily as shown in Figure 7 for different fertiliser treatments. The results are as presented in Table 11. The percentage error obtained for treatment using 376 kg/ha of fertiliser on grain yield was 6.5%, while for harvest index it gives error of 0.09 (26.5%). In the case of treatment without fertiliser, error was 5.7% in grain yield and 0.03 (6.3%) in harvest index. With 156 kg/ha of fertiliser, as recommended by the Rice Research Center, the error was 3.5% in grain yield and 0.07 (15.9%) in harvest index. The model was not able to simulate the physical maturity day as error is high in all the cases. With 376 kg/ha of fertiliser as used by the farmers, the yield obtained was 3280 kg/ha which was less than the 3430 kg/ha of yield obtained by using 156 kg/ha of fertilisers. Also the harvest index was reduced while using excess of fertilisers.

The percent errors between the observed and simulated yields ranged from 3.5–6.5%, whereas the percent errors between the observed and simulated harvest indices were 6.3– 26.5%. The errors up to 15% are considered acceptable for yield modelling studies. Soler et al. (2007), who used the DSSAT CERES-MAIZE model to estimate actual yields of rain fed and irrigated maize genotypes, in the state of São Paulo, Brazil reported percent errors in the range from –10.7 to 11.3%. It is important to note that the models used in this study accounted only for the effect of weather variables such as solar radiation, photoperiod, temperature, and rainfall. Other factors such as the occurrence of pests, diseases, and nutritional deficiency were not considered in the field trials. These might explain part of the bigger errors (>15%) observed in two cases for the harvest indices.

Table 11 Observed and Simulated Yield Components for the Experiment at Roi Et for Cultivar RD6

	Grain Yield (kg/ha)			**Harvest Index**			**Physical Maturity Day**		
Fertiliser 16-16-8	Sim	Obs	% error	Sim	Obs	% error	Sim	Obs	% error
376 kg/ha	3081	3280	6.5	0.34	0.43	26.5	236	183	–22.5
0 kg/ha	2734	2890	5.7	0.48	0.51	6.3	158	183	15.8
156 kg/ha	3314	3430	3.5	0.44	0.51	15.9	158	183	15.8

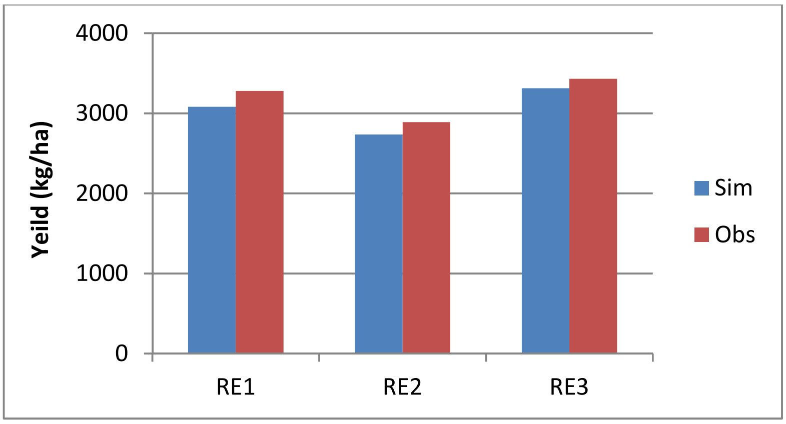


Figure 6 Simulated and observed yield for RD6 at Roi Et

Roi Et for Cultivar KDML105

The yield of KDML105 in Roi Et was much less than the average yields of KDML105 in Northeast Thailand. This may be due to soil and weather conditions which do not favour KDML105. On the other hand, RD6 performed much better in this region, so it can be inferred that this location was more suitable for RD6 then KDML105. DSSAT model simulated the crop growth parameters satisfactorily with an error of 6.4% in grain yield and 0 error in harvest index in the condition without using fertilisers. With the use of fertilisers, as in normal farmer practice, yield shows an error of 0.5% and harvest index has an error of 0. The physical maturity day was also simulated satisfactorily in both the experiments. The results are as presented in Table 12.

Table 12 Observed and Simulated Yield Components for the Experiment at Roi Et for Cultivar KDML105

	Grain Yield (kg/ha)			Harvest Index			Physical Maturity Day		
	Sim	**Obs**	**% error**	**Sim**	**Obs**	**% error**	**Sim**	**Obs**	**% error**
No fertiliser	1304	1220	–6.4	0.48	0.48	0.0	140	149	6.4
Fertiliser 16-16-8 @ 157kg/ha	1801	1810	0.5	0.39	0.39	0.0	157	149	–5.1

Drought Response experiments conducted at Ubon and Khon Kaen

These experiments were performed at the Rice Research Centers to test the impact of drought conditions prevailing at various growth stages of rice crop. The conditions are mentioned as fully irrigated at URRC (Ubon1), rain fed (Ubon2), rain fed with late seeding (Ubon3), and rain fed at Khon Kaen (CP1). The various yield components as observed during the experiments and as simulated by the DSSAT model are presented in Table 13. The results indicated that the model simulated grain yield and anthesis day satisfactorily in all the cases with error value less than

10%. The harvest index was also simulated well except in the case Ubon 3 where error value is 15.2%. The observed and simulated yield in all four cases considered here is shown in Figure 7.

Table 13 Observed and Simulated Yield Components for the Drought Response Experiments at Ubon (URRC) and Chum Phae (CPRRC)

	Grain Yield (kg/ha)			**Anthesis Day**			**Harvest Index**		
	Sim	**Obs**	**% error**	**Sim**	**Obs**	**% error**	**Sim**	**Obs**	**% error**
Fully Irrigated at URRC	3883	3750	–3.4	78	77	–1.3	0.44	0.44	0.0
Rain fed at URRC	3360	3360	0.0	80	87	8.8	0.38	0.4	5.3
Rain fed with late seeding dates at URRC	2771	2720	–1.8	69	73	5.8	0.33	0.38	15.2
Rain fed at CPRRC	3045	2940	–3.4	93	85	–8.6	0.39	0.42	7.7

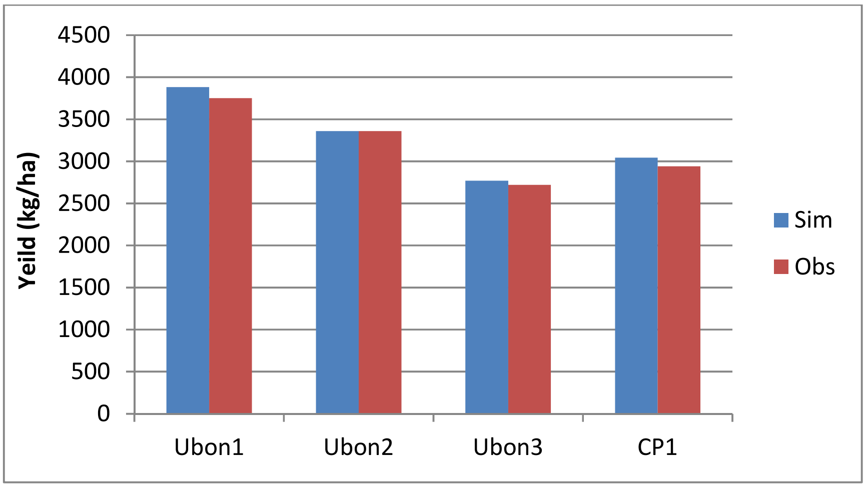


Figure 7 Observed and simulated grain yield for the drought response experiments at Ubon and Chum Phae

4.2 Simulated and observed weather data

The monthly total rainfall and monthly minimum and maximum temperatures averaged for the baseline period 1981–2000 were used to check the performance of the simulated data. The cumulative rainfall with observed and simulated data was in close agreement for all three provinces, as shown in Figure 8. The cumulative rainfall values with simulated and observed weather data for Roi Et was 1365 and 1382 mm, Ubon was 1379 and 1389 mm and Khon Kaen was 1256 and 1222 mm. Good agreement in simulated and observed rainfall is also reflected in the coefficient of determination (R^2) of 0.61, 0.68, and 0.61 for Roi Et, Ubon Ratchathani, and Khon Kaen Provinces, respectively.

The minimum and maximum temperature values from observations and as simulated using LARS-WG are shown in Figure 9 for three Provinces Roi Et, Ubon Ratchathani, and Khon Kaen. The results indicate that the model simulated the Tmin and Tmax values satisfactorily at all the three provinces. The R^2 value for Tmin is 0.89 and for Tmax is 0.74 at Roi Et Province. Similarly the R^2 value is 0.84 and 0.71 for Tmin and Tmax at Ubon.

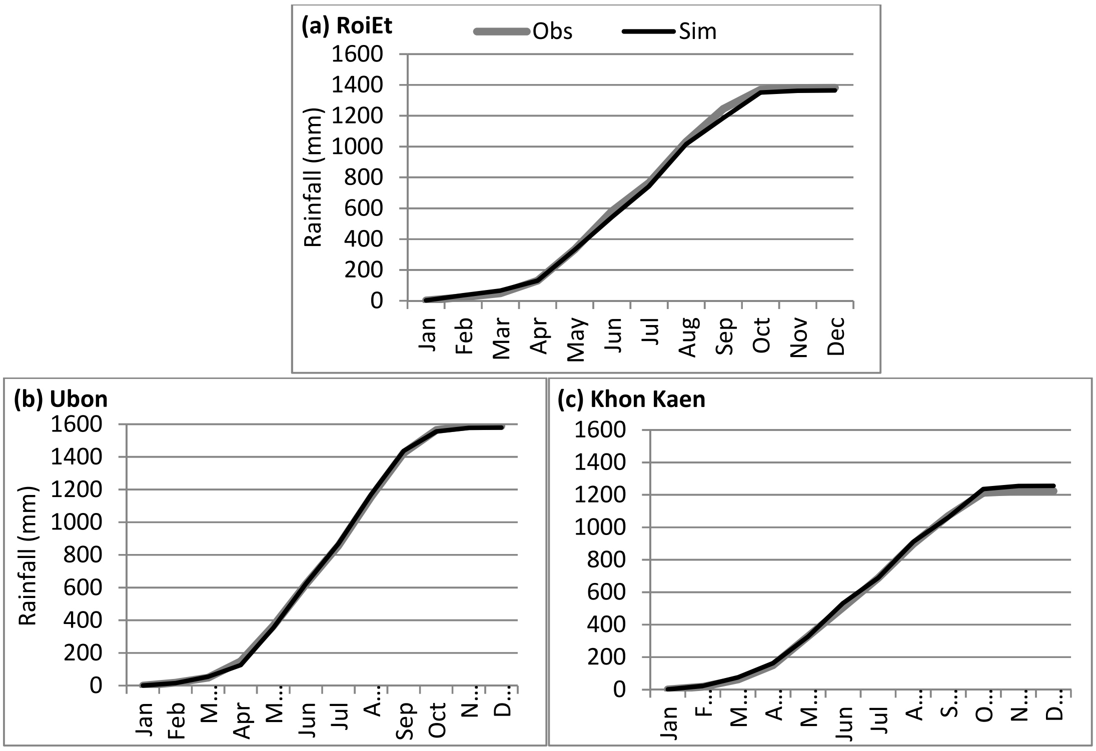
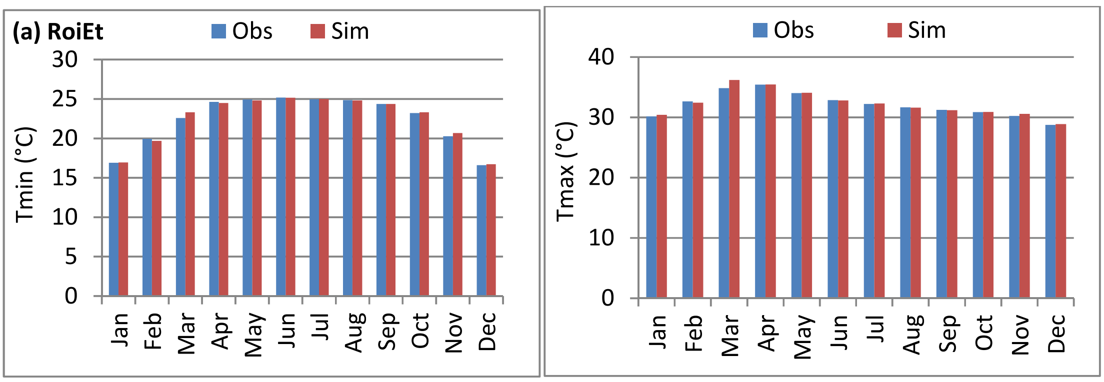


Figure 8 Observed and simulated cumulative monthly rainfall for the baseline period (1981–2000) at Roi Et, Ubon and Khon Kaen



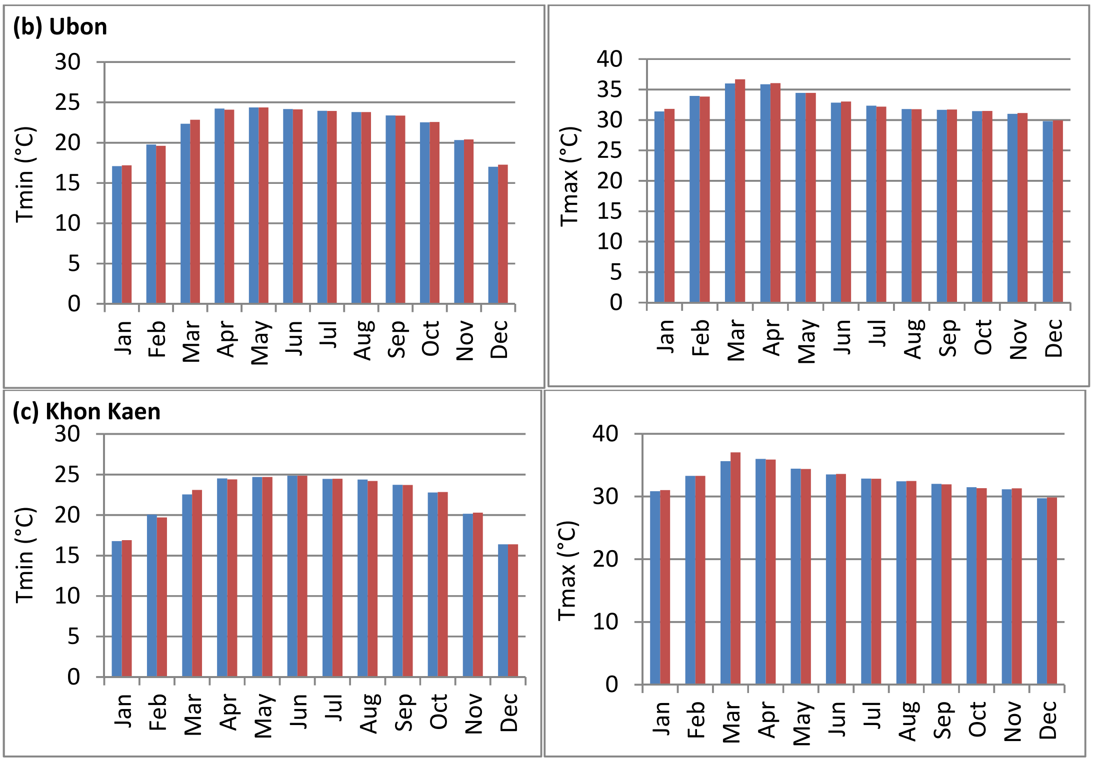


Figure 9 Observed and simulated monthly minimum (Tmin) and maximum (Tmax) temperatures averaged for 1981–2000 at Roi Et, Ubon and Khon Kaen

4.3 Impact on rice yield

The rice yield was projected using the downscaled GCM data for the three future periods. The projected yields are presented in Table 14 for HAdCM3 A2 scenario and in Table 15 for HadCM3 B1 scenario. Based on the climate projections for HadCM3 both A2 and B1 scenarios, the rice yield is projected to change by small amount during early and mid-century period in all three Provinces. The change in yield is projected to decrease by 6.1, 1.3, and 7.8% under A2 scenario during the late century period in Khon Kaen, Roi Et and Ubon Ratchathani Province, respectively. Under B2 scenario change in yield does not show any clear pattern of increase or decrease. In a similar study by Babel et al. (2011), significant decrease in yield was projected (Table 16) based on the climate change projections from ECHAM4 GCM.

Table 14 Simulated rice yield and changes (%) for future periods based on HadCM3 simulated climate under A2 scenario

Location	1981-2000	2011-30		2046-65		2080-99	
	Yield (Kg/ha)	Yield (Kg/ha)	% change	Yield (Kg/ha)	% change	Yield (Kg/ha)	% change
Khon Kaen	4495.7	4428.8	–1.5	4500.3	0.1	4222.5	–6.1
Roi Et	2191.9	2175.1	–0.8	2196.6	0.2	2163.8	–1.3
Ubon	2885.0	2878.3	–0.2	2813.5	-2.5	2659.0	–7.8

Table 15 Simulated rice yield and changes (%) for future periods based on HadCM3 simulated climate under B1 scenario

Location	1981-2000	2011-30		2046-65		2080-99	
	Yield (Kg/ha)	Yield (Kg/ha)	% change	Yield (Kg/ha)	% change	Yield (Kg/ha)	% change
Khon Kaen	4495.65	4327.73	-3.74	4504.55	0.20	4561.15	1.46
Roi Et	2191.85	2178.87	-0.59	2202.55	0.49	2211.25	0.89
Ubon	2884.95	2901.80	0.58	2849.60	-1.23	2722.75	-5.62

Table 16 Simulated rice yield and changes (%) for future climate scenarios

Location	1997-2006	2020-29		2050-59		2080-89	
	Yield (kg/ha)	Yield (kg/ha)	Change (%)	Yield (kg/ha)	Change (%)	Yield (kg/ha)	Change (%)
Ubon	2732	2427	–11.16	2200	–19.47	1855	–32.10
Khon Kaen	2807	2101	–25.15	1883	–32.91	1901	–32.27
Roi Et	2128	1764	–17.11	1481	–32.11	1944	–8.64

Source: Babel et al. (2011)

5 Recommendations for adaptation measures

The rice yield in Northeast region of Thailand is lower than the country average. The dependence on rain and low fertility of soil are the main reasons for the lower yield. The future climate change is further projecting the negative impacts on rice yield in the region. By changing some of the management practices such as changing the planting dates, methods of tillage, application of fertilisers, and change in rice varieties might help improve the yield in the region. In the study by Babel et al. (2011) various alternate crop management practices, including different sowing dates, rates of nitrogen fertilisers, time of application of nitrogen fertiliser, and different depths of tillage operation were investigated as adaptation measures to mitigate the effects of climate change on rice yield. Based on the analysis in this study the various possible adaptation measures for the Northeast of Thailand are:

- Development of irrigation facilities, as most of the rice production in the region is rain fed which is facing many uncertainties due to abnormal weather behaviour. The weather is expected to change in future periods with high variability in rainfall. Thus developing the irrigation facilities in the region may help overcome the water stress of the rice crop during various critical growing phases.
- The two rice varieties RD6 and KDML105 are grown in most of the Northeast of Thailand. The use of some other varieties which have more tolerance to droughts or floods might be used in the region based on the future climatic conditions.
- The experiments to optimise the use of fertilisers were conducted by the Rice Research Centers, the data for which were used in this study. More such experiments are required in the region along with new rice varieties and irrigation facilities.
- In future period temperature is projected to increase which might bring the negative affect on the rice yield. Shifting the planting dates so as to save the crop form high temperature

during critical stages might help mitigate the native impacts of climate change in future periods.

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