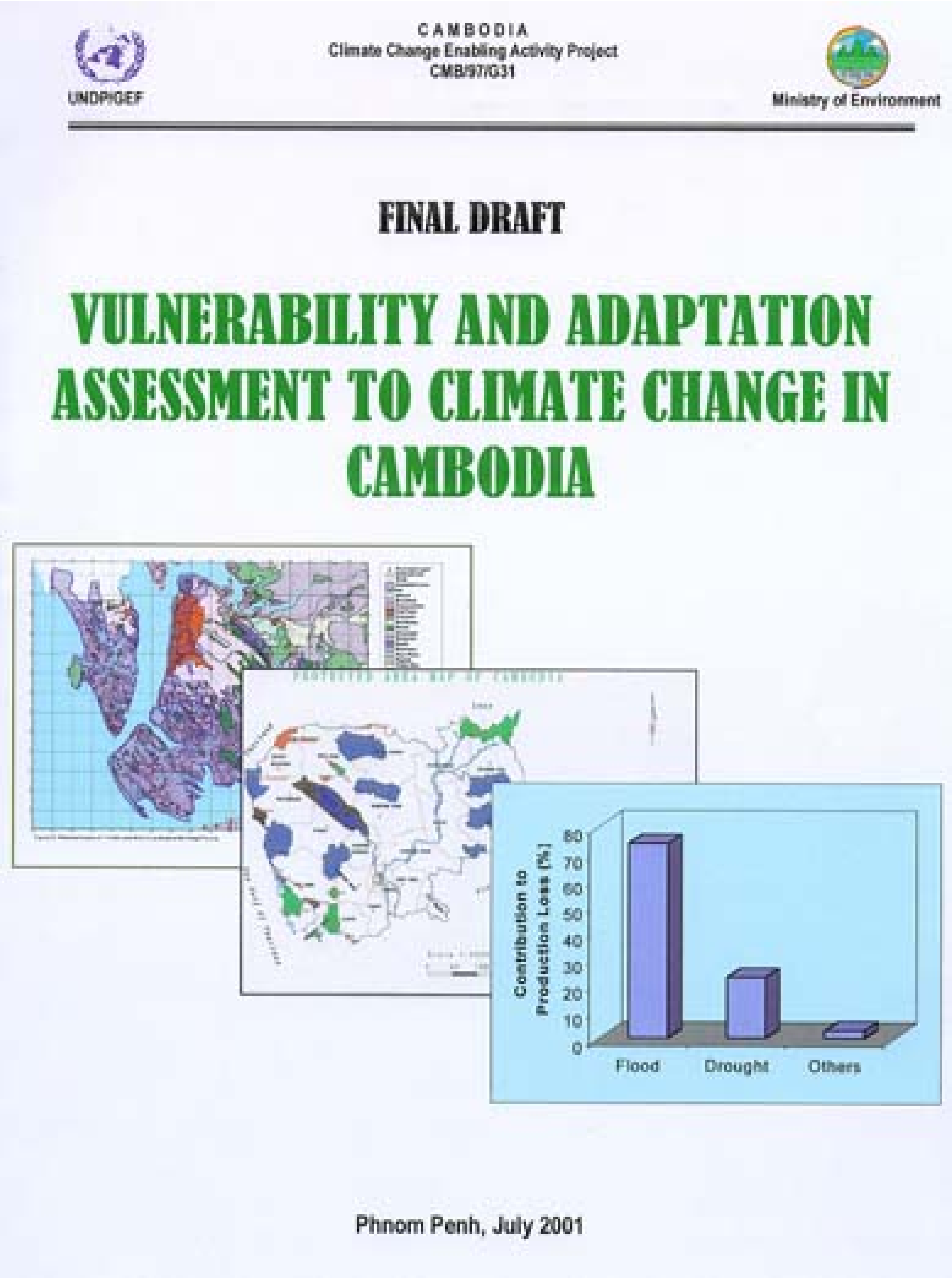

UNDP/GEF

CAMBODIA
Climate Change Enabling Activity Project
CMB/97/G31

Ministry of Environment

FINAL DRAFT

VULNERABILITY AND ADAPTATION ASSESSMENT TO CLIMATE CHANGE IN CAMBODIA

Phnom Penh, July 2001

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Front cover maps and chart: (1) Potential impacts of 1m sea level rise on land use in Koh Kong province (Climate Change Project), (2) Cambodia's Protected Areas System (Ministry of Environment), (3) Contribution of natural hazard to rice production loss in Cambodia (Climate Change Project).

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ABBREVIATIONS

ADB	Asian Development Bank
AFP	Acute Flaccid Paralysis
AMT	Annual Mean Temperature
ARI	Acute Respiratory Infection
CA	Cluster Analysis
CCSR-NIER	Centre for Climate Research Studies/NIER Transient (Japan)
CF	Correction Factor
CH_4	Methane
CO_2	Carbon Dioxide
CSIRO2-EQ	Commonwealth Scientific and Ind. Research Org., Mark2 (Australia)
CV	Coefficient of Variability
DHF	Dengue Fever
Dn80s	1980s net Deforestation
DS	Dry Season
DSR	Dry Season Rainfall
ENSO	El-Nino Southern Oscillation
EU	European Union
ExTCs	Extreme Tropical Cyclones
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GHG	Greenhouse Gas
GIS	Geographical Information System
HYV	High Yielding Varieties
ID	Identification
IO	International Organization
IPCC	Intergovernmental Panel on Climate Change
IS92a-f	IPCC 1992 a-f emission scenarios
LAPAN	Lembaga Penerangan lan Antonkga Nasdal
MAFF	Ministry of Agriculture Forestry and Fisheries
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MoE	Ministry of Environment
N_2O	Nitrous oxide
NCSP	National Communication Support Program
NGO	Non Governmental Organization
Oxfam GB	Oxfam Great British
PCA	Principal Component Analysis
PL	Percent of Literate
ppmv	Part Per Million by Volume
SCENGEN	A global and regional SCENario GENerator
SO_2	Sulphur dioxide
SRES	Special Report on Emissions Scenarios
SRESA2	Special Report on Emissions Scenarios as Reference
SRESB1	Special Report on Emissions Scenarios as Policy
STS	Storm Tropical Storm
TB	Tuberculosis
TgS	Teragram Sulphur

TS	Tropical Storm
TY	Typhoon
UNDP	United Nations Development Program
UNEP	United Nation Environmental Program
US-CS	United States Country Studies
VAC	Volume of Potentially Available for Cutting
VOB	Volume Over Bark
w.r.t.	With Respect To
WHO	World Health Organization
WMO	World Meteorological Organization
WS	Wet Season
WSR	Wet Season Rainfall

UNITS

1 tonne (t) = 1x10^6 grams
1Gg = 10^3 t
1Gg = 10^9 g
1 t = 1 megagram
1t = 10^6g

Multiple	Prefix	Symbol
10^3	kilo	k
10^6	mega	M
10^9	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E

PREFACE

Climate change is one of the most serious global problems which has brought countries throughout the world to work together to mitigate the problem under an international convention called the United Nations Framework Convention on Climate Change (UNFCCC). The Kingdom of Cambodia ratified the Convention on 18th December 1995 and the Convention entered into force on 17th March 1996. Through an agreement between the Government of Cambodia and UNDP/Global Environment Facility (GEF), Cambodia has received funding from UNDP-GEF to carry out a three-year project called *Enabling Cambodia to Prepare its First National Communication in response to the UNFCCC* (Climate Change Enabling Activity Project: CCEAP). This project started in January 1999 with the aim of assisting Cambodia to prepare its First National Communication in response to the UNFCCC.

The first National Communication under the UNFCCC is mandatory for countries that have ratified the convention. For Cambodia, the steps to be taken in the preparation of this communication are:

- Establishment of a national green house gas (GHG) inventory;
- Assessment of GHG mitigation options; and
- Assessment of the vulnerability of Cambodia to climate change and development of adaptation options to cope with the climate change.

The vulnerability and adaptation assessment to climate change in Cambodia was carried out by the National Technical Committee (NTC), members of which are representatives from Ministry of Environment; Ministry of Agriculture, Forestry and Fisheries; Ministry of Public Works and Transport; Ministry of Water Resources and Meteorology; Ministry of Industry, Mines and Energy; and the Royal University of Phnom Penh.

This report discusses the vulnerability of agriculture and forestry sectors, human health and coastal zone to climate change. Some of the adaptation options that are in line with the government development plans are proposed. In the preparation of this report, we have received support from many organizations and individuals. We would like to take this opportunity to sincerely thank all of them. Support provided by Dr. Rizaldi Boer, a consultant from the Indonesian Bogor Agricultural University, is greatly appreciated. His technical and advisory assistance has been a very valuable contribution towards completion of this report and building technical capacity of the government counterparts. We also thank the GIS team of the Ministry of Environment who has provided significant help to the Project in the analysis of the coastal zone. And last but not least, we would like to express our special gratitude to the UNDP Office in Phnom Penh for its valuable support and close cooperation in conducting this study.

Finally, we realize that many things still need to be done in the future. We are always open to constructive inputs, which, we believe, could improve our future studies.

August 2001

Dr. Mok Mareth
Minister for the Environment

EXECUTIVE SUMMARY

Introduction

Many studies have indicated that the atmosphere under elevated CO_2 concentration is warming and may have significant impact on global climate. If the rate of increase of greenhouse gas (GHG) emissions is not reduced, the global climate will change. Therefore, in many countries governments are seeking advice from a wide range of disciplines on the potential impacts of climate change on the environment and their society and economy. This study is conducted in order to assess the impact of climate change on some priority sectors in Cambodia and to identify adaptation options in the related sector to the changing climate. The study was conducted by the National Technical Committee of the UNDP/GEF sponsored Cambodia's Climate Change Enabling Activity Project based in the Ministry of Environment. The study was conducted following several steps of analysis as shown Figure 1.

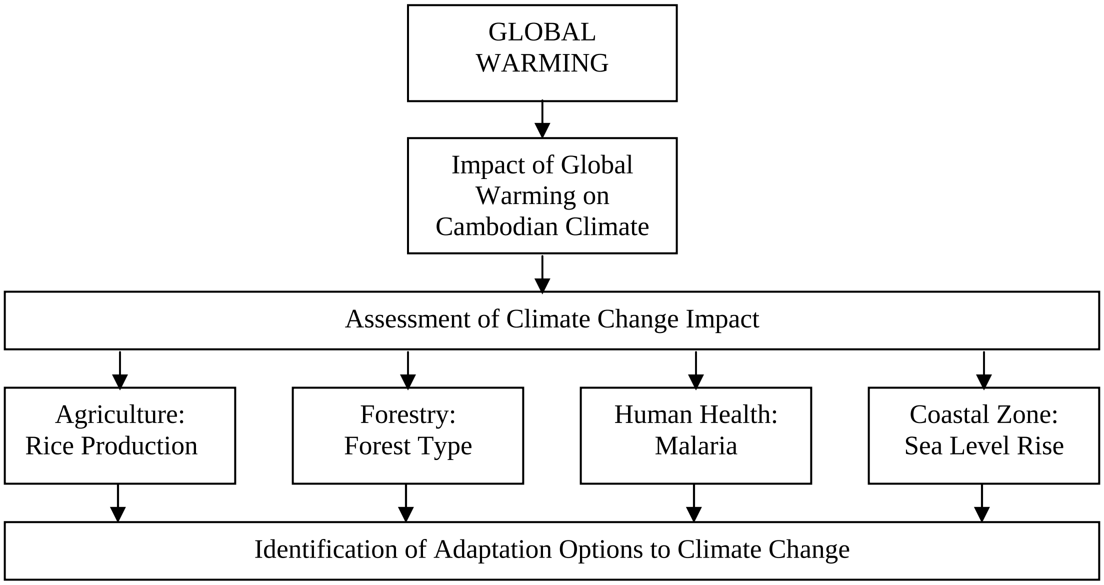


Figure 1: Steps of Analysis

Impact of Global Warming on Cambodia's Climate

The global warming scenarios used in this study are SRESA2 and SRESB1. SRESA2 describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slow. SRESB1 describes a convergent world with the same global population that peaks in mid-century and declines thereafter, rapid change in economic structures towards a service and information economy, with reduction in material intensity, and the introduction of clean and resource-efficient technology. With these characteristics, the SRESA2 will lead to higher future GHG emissions while SRESB1 leads to lower future GHG emissions. The global temperature and sea level rise under these two scenario is presented in Table 1.

Table 1: Temperature and Sea Level Rise Relative to 1990

Year	**2000**	**2025**	**2050**	**2100**
Global Temperature (^oC):				
SRESA2: Best guess	0.2	0.5	1.2	2.9
: Range	0.15-0.25	0.3-0.7	0.8-1.6	2.0-4.1
SRESB1: Best guess	0.2	0.7	1.1	1.9
: Range	0.15-0.25	0.5-0.9	0.7-1.6	1.2-2.7
Sea Level (cm):				
SRESA2: Best guess	2	10	21	60
: Range	0-4.0	4.0-20	9.0-41	25-112
SRESB1: Best guess	2	10	21	48
: Range	0-4.0	4.0-22	9.0-42	18-85

The impact of global warming on Cambodia's Climate was assessed using two GCM models, i.e. CCSR and CSIRO. From validation of this study, it was indicated that the two GCM models used in this analysis (CCSR and CSIRO) were not very suitable for use in Cambodia because the two models were developed for use Japan and Australia which are very different geographical region. The deviation of GCM models from the observed rainfall data was very significant. The deviation of monthly wet season rainfall could reach 794 mm, especially during the rainy season. Therefore, correction factors were develop and used in the subsequent analysis.

Under SRESA2 scenario and using CSIRO model, it was estimated that temperature in Cambodia would increase up to 2.0^{o}C, while using CCSR model it would increase up to 2.5^{o}C. Under SRESB1, the increase was much smaller, i.e. 1.35^{o}C under CSIRO and 1.60^{o}C under CCSR. Rainfall in Cambodian would also increase from the current condition. The magnitude increase also varies with location, time, GCM models and emission scenario. Low land areas seem to be more affected than high land areas. Under SRESA2, annual rainfall in 2100 would increase between 3 and 35% from the current rainfall depending on location, while under SRESB1 the increase is smaller.

Impact of Climate Change on Sectors

The impact of climate change on sectors was assessed using analog and modeling approaches. Analog approach used past experiences to assess the possible impact of climate change in the future, while modeling approach used statistical model to express the relationship between the variability of climate and sectors' outputs.

Agriculture

In the agriculture sector only rice production system was assessed. Based on the past five year data, rice production loss in Cambodia was mainly due to the occurrence of flood (more than 70%), followed by drought (about 20%) and others such as pest and diseases (10%). However, the occurrence of flood and drought were not always associated with the occurrence of ENSO events.

Based on field observations, flooding mostly occurred due to the increase in water levels of the Mekong River and Tonle Sap Lake. These two water bodies link each other. The Mekong River starts from the Tibet Plateau. The increase of water level in the Mekong is closely related with the rainfall throughout the Mekong basin. This might explain why the flood occurrence was not always related with Cambodian rainfall. For future study the relationship between water flow in the Mekong River and Tonle Sap Lake and rainfall variability in the entire basin as well as relationship between ENSO and rainfall variability in the basin need to be investigated. By increasing our understanding on this issues, the timing and the intensity of flood and drought events in rice growing areas of Cambodia can be better estimated. Some studies indicated that intensity and the frequency of ENSO event under changing climate might increase.

Using statistical modeling, it was found that the yield anomaly of wet season rice was positively correlated with May rainfall while dry season rice was negatively correlated with March Rainfall. Positive correlation for wet season rice is expected since water shortages that occur during May (early stage of development or vegetative growth for wet season rice) may reduce yield significantly. Negative correlation for dry season rice is expected since high rainfall in March may give negative impact to rice yield. During this month crop requires more radiation for seed filling and ripening. Using this statistical model, mean of yield anomaly of wet season rice in Battambang, Prey Veng, Takeo, and Kampong Cham (provinces which contributed to more than 50% of national rice production) under changing climate would be more than zero while those of dry season rice would be less or equal to zero. These mean that under changing climate the yield of wet season rice would increase while that of dry season rice would remain the same or decrease. However, there is a chance that under changing climate rice yield in some provinces would be more variable than current conditions due to the increase in flood frequency and intensity, in particular in rice growing areas surrounding Tonle Sap Lake and Mekong River.

Rice production in Battambang, Prey Veng and Takeo in 2000 exceeded the demand of the corresponding provinces, while at Kampong Cham there was a deficit of about 100,000 tonnes. Under changing climate, rice production in the four provinces are over the demand if the government could increase rice productivity by about 1 t/ha per 25 years from the current productivity. In 2025, rice production from these four provinces can meet 56% of the national demand and in 2050 it increases to 67% under SRESA2 scenario and 65% under SRESB1 scenario. In 2100, under SRESA2 contribution of these four provinces to the total national demand is almost the same as in 2050 while under SRESB1 it is lower. Nevertheless, as this study used statistical modeling some of determinant factors in crop growth and development are not taken into account. Further studies for verification is therefore recommended. The use of deterministic modeling approach will be able to capture more factors that contribute to variability of yield.

Forestry

According to the Holdridge Classification System, under current climatic conditions Cambodia's forest is dominated by dry forest (60%), followed by wet forest (20%) and moist forest (20%). Under changing climate, the area of wet forest would decrease while moist forest would increase and dry forest would remain the same. This change indicated that forest productivity and biodiversity might also change. The high rate of deforestation may accelerate the loss of forest biodiversity and reduce forest productivity due to the increase in human activities in the forest areas. The magnitude of change in the forest area due to climate change depends on GCM model and emission scenarios used in the analysis. In this study, the pattern of change of forest type due to climate change was quite similar in both CCSR and CSIRO. Further study on the impact of climate change on forest biodiversity and forest productivity needs to be carried out. Based on studies of other neighboring countries, there is a possibility that under changing climate forest productivity of Cambodian forest may change and some of the species may disappear. However, this study will require more data in terms of quantity and quality, where this is the main problem faced by the country.

Human Health

The impact of climate change on human health is not well understood. However, it was reported that climate change would have indirect and direct impacts on human health. The direct impacts include exposure to thermal extremes. Frequency and/or intensity of extreme weather events may increase and this could result in death, injuries, psychological disorders, and damage to public health infrastructure. Whereas the indirect impacts include the disturbances of ecological ecosystems that cause changes in geographical range and the incident of vector-borne diseases, infectious diseases, malnutrition and hunger which in turn disturb child growth and development. Furthermore, sea level rises may force population displacement and cause damage to infrastructure. This will lead to increased risk of infectious diseases and psychological disorders.

In this study the impact of climate change was only assessed on number of Malaria cases. Based on monthly historical data from 1996-1999, variability of malaria cases in Cambodia can be explained mostly by wet season rainfall (WSR), dry season rainfall (DSR), mean annual temperature (T_{mean}) and percent literate people (PL). Percent literate contributed to about 46% of total variation of malaria cases, while wet season rainfall 29%, mean annual temperature 19% and dry season rainfall 6%. The form of the relationship is as follows:

$$Y = 24{,}268 - 1.37\ DSR + 1.55\ WSR - 103\ T_{mean} - 342PL$$

This result suggests that the promotion of education schemes will have positive impacts on a malaria incidence. Other factors for welfare such as safe water supply, good sanitary facility and hygiene education should also strongly influence the number of cases. Under changing climate, it was found that the average number of malaria cases in most of provinces in Cambodia would consistently decrease under SRESB1 scenario ranging from –1 to –62%. In contrast, under SRESA2 the number of malaria cases gradually increases ranging from –1 to 16%. For future studies, it is recommended that the model to estimate malaria cases needs to be improved using longer historical data and to cover most of the sensitive areas. Continued observation and good database management would be priority activity for facilitating the studies.

Coastal Zone

The coastal zone of Cambodia consists of three provinces (Kampong Som, Kampot, and Koh Kong) and one autonomous city Kep). The total area covered by these provinces and the autonomous city is about 17,237 km^2. In this study, only Koh Kong province has been assessed since this province covers over 64% of the coastal zone (11,160 km^2) and is the most vulnerable to the impact of sea level rise according to a preliminary analysis of 1 m sea level rise impacts on the Cambodian coastal zone. This is due to the fact that most areas along the coastline in this province are lowlying. The study indicated that if sea level rises by up to 1 m, about 0.4% (4,444 ha) of the area would be under water (Table 2). Table 1 shows that the sea level under the two scenarios would rise by about 0.5 m. If the sea level rise was only 0.5 m, only small areas would be under water. However, if the global effort to reduce GHG emissions is not carried out (SRESA2 scenario), rainfall might increase under changing climate and the water flow from the river may also increase and as a result the area close to the riversides might be exposed to frequent floods. Under SRESA2 scenario, the rainfall in the main four river basins (Stung Metoek, Stung Russei Chrum, Stung Sala Munthun, and Stung Chhay Areng) of the Koh Kong province would increase between 2% and 15% and this would be translated to the increase in water flow of the four river basins between 2 and 10 m^3/s. Under SRESB1, the rainfall might decrease between 2% and 5% and this might not have significant impact on the river flow.

Table 2: Area of Land to be Lost in Case of Sea Level Rise by 1 m in Koh Kong Province

No.	I. Description	**Area under Water (ha)**
1	City/Town	279.6
2	Village	77.9
3	Swimming Beach	10.4
4	Marsh	32.5
5	Forest	181.8
6	Secondary Forest	3.5
7	Shrub	12.7
8	Mangrove	3,114.3
9	Grassland	301.2
10	Rice Paddy	29.6
11	Crops	9.8
12	Shrimp Farm	345.2
13	Others	46.0
	Total	**4,444.1**

Adaptation to Climate Change

Agriculture

The impact of climate change on rice production in Cambodia would not be substantial if the government could meet the existing 1999-2010 Agriculture Development Plan. Studies in the four provinces indicated that from 2025 to 2100, the rice production would exceed demand, if rice productivity were increased by about 1t/ha per every 25 years from the current productivity.

Adaptation options that have been identified for increasing rice productivity under changing climate are the following:

- Improvement of genetic or development of new high yielding varieties;
- Improvement of crop management and cultural practices;
- Development of capacity to adapt to current extreme climate such as development of early warning system to extreme climate, development maps showing the provinces of rice growing areas prone to flood and drought;
- Development of irrigation facilities in many parts of low land areas;
- Increasing planting index in suitable areas; and
- Diversification of foods.

Forestry

In forestry sectors, there are at least three options that can be done to reduce the impact of climate change namely:

1. Forest Plantation Establishment

Promotion of forest plantation establishment is important to relieve pressure on the natural forests. The optimal use of unproductive land for forest plantation establishment should be encouraged. Tree species used in the designated areas should match with socio-economic and biophysical conditions of the areas as well as global markets. Therefore, maps of land quality index for tree plantations should be verified or established.

2. Conservation of Protected Areas

There is a need for establishment of appropriate legal and policy frameworks, protected area management plans, and an effective monitoring system. Strengthening law enforcement and community participation in protected area management are also critical. Programmes for protecting critical wildlife habitats and for the expansion of species and forest communities should also be enhanced in particular in the likely affected areas. Programmes to rehabilitate the protected forests also need to be promoted through enhanced natural regeneration techniques using native and exotic tree species.

3. Improvement of Forest Resource Management

The common goal of forest management is to achieve sustainable management through the utilization of forest resources in sustainable ways. Partially, this can be done through the promotion of improved silvicultural systems and techniques to forest concession holders, such as techniques to reduce the impact of logging.

Human Health

For the health sector, control measures being introduced to reduce malaria cases are through early diagnosis and treatment of the diseases, utilization of parathyroid treated mosquito nets by communities living in high risk areas to control the vectors, strengthening program management and supervisory practices and increasing funds for the provision of mosquito nets and insecticides. In addition, information, education and communication (IEC) programs for health such as increasing community understanding on the most critical causes of disease -- watercourses and containers where mosquitoes' breed; personal habits, which are conducive to the attack of parasitic and infectious organisms -- should be widely introduced and promoted. Low cost preventative methods such as improvement of personal hygiene and surrounding environments by destroying the insect breeding sites, using bed nets, etc. should also be promoted and expanded. The education materials should be simple as the level of education in rural communities is rather low.

Coastal Zone

Considering the possible impact of sea level rise on the coastal zone is important for the government as it would have a very significant impact on the country. Possible measures for consideration include:

- Develop a national strategic response to sea level rise for the coastal areas;
- Investigate further potential impacts of sea level rise on biogeophysical, socio-economy, marine resources, freshwater, infrastructure, human settlements, and agricultural production;

- Formulate a comprehensive adjustment and mitigation policy for sea level rise in the context of integrated coastal zone management;
- Develop computer-based information systems covering the results of surveys, assessments and observations in order to minimize the impact of sea level rise resulting from climate change;
- Increase public awareness on the effect of sea level rise on Cambodia’s coast;
- Identify potential donors either multilateral or bilateral sources to assist the country in adaptation to sea level rise; and
- Establish cooperation frameworks, training, technology transfer, surveillance of climate change in case of sea level rise, and the sharing of experiences to assist the government in establishing preparedness response to climate change.

I. GENERAL INTRODUCTION

Many studies have indicated that the atmosphere under elevated CO_2 concentrations is warming and may have a significant impact on global climate. A study conducted by LAPAN-Indonesia indicated that elevated CO_2 would affect the occurrence of El-Nino Southern Oscillation (ENSO) (Ratag *et al.*, 1998). It was shown that at present conditions ($1xCO_2$), the frequency of ENSO occurrence is once every 3-7 years. The frequency would increase to once every 2-5 years at $2xCO_2$ and once every 2-3 years at $3xCO_2$. However, other studies gave different results. Global warming only caused a little change or a small increase in amplitude for El Nino events over the next 100 years (Trenberth and Hoar, 1996). Therefore, the question that arises regarding global warming and its relation with ENSO events is that of the confidence of projections. Irrespective of that confidence, with little or no change in El Nino amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Nino events in many different regions. It has been reported that most South-Asian countries suffered from drought/flood during ENSO events and these natural hazards caused serious economic loss.

The increase of CO_2 concentration in the atmosphere also has direct effects on crop growth. Under elevated CO_2, photosynthesis rate increases while transpiration rate decreases (Acock, 1990). This effect is more pronounced in C_3 plants (crops with low photosynthetic efficiency) than in C_4 plants (crops with high photosynthetic efficiency), because C_3 has lower photosynthetic capacity. Under elevated CO_2, this capacity would increase. Further effect of this, most of vegetative organs of crops increase. However, such increase will occur if environmental factors affecting crop growth such as rainfall, temperature, nutrients etc are optimal, and these may not occur in reality. Climatic conditions under elevated CO_2 will change and this may have negative effect and offsets the benefit of increasing the photosynthesis. In addition, the increase of extreme events under elevated CO_2 will damage the ecosystem. Therefore, there is a need to study the vulnerability of all sectors in a country to the changing climate and develop options to adapt to these possible changes.

General Circulation Models (GCMs) have commonly been used for assessing the impact of elevated CO_2 on climate (Gates *et al.*, 1990). GCMs are mathematical representations of atmosphere, ocean and land surface processes based on the law of physics. Such models consider a wide range of physical processes that characterize the climate system. These models estimate changes of dozens of meteorological variables in regional climates in grid boxes that are typically 250 km in width and 600 km in length or 3^o or 4^o up to 10^o (latitude and longitude). As the resolution of these models is very low, their ability to accurately represent regional climate is low. In many regions, GCMs may significantly underestimate or overestimate current temperatures and precipitation (IPCC, 1996). An additional disadvantage of GCM-based scenarios is that a single GCM, or even several GCMs, may not represent the full range of potential climate changes in a region.

Concentration of future GHGs in the atmosphere is greatly dependent on the rate of the GHG emission. The rate of emissions would be a function of several driving forces such as demographic development, socio-economic development, and technological change (IPCC, 2000). The IPCC (Intergovernmental Panel on Climate Change) has released six scenarios in 1992 called IS92 and 40 new scenarios in 1998 called SRES. These scenarios described an emissions future reflecting different assumptions about population and economic growth, and energy technology and efficiency. However, these scenarios do not take into account specific climate policy interventions or the introduction of GHG emission targets.

The National Communication Support Program (NCSP) has endorsed the use of MAGICC-SCENGEN (Hulme *et al.*, 2000), a program which links emission scenarios with global and regional climate change. This program is useful for vulnerability and adaptation assessment studies. In this program, MAGICC (model for the assessment of greenhouse-gas induced climate change) uses a series of reduced-form models to emulate the behavior of fully-three dimensional dynamic GCMs. It calculates the annual-mean global surface air temperature and global-mean sea-level implication of emissions scenarios for GHGs and sulfur dioxide (Raper *et al.*, 1996). Whereas SCENGEN (a global and regional scenario generator) is a simple database that contains the results of a large number of GCM experiments, as well as an observed global and four regional climate data sets. These various data fields are manipulated by SCENGEN, using the information about the rate and magnitude of global warming supplied by MAGICC and directed by user's choice of important climate scenario characteristics (Hulme *et al.*, 2000).

The objectives of the vulnerability and adaptation assessment for Cambodia are:

- To evaluate briefly the impact of ENSO occurrence on Cambodia's climate;
- To evaluate the performance of GCMs in Cambodia;
- To evaluate the impact of increasing GHG concentrations in the atmosphere on Cambodia's climate using the selected GCMs;
- To assess the vulnerability of agriculture, forestry, human health and Cambodia's coastal zone to climate change; and
- To develop adaptation options to climate change in agriculture and forestry sectors, human health and for the coastal zone.

I.1. REFERENCES

Acock, B. 1990. Effects of Carbon Dioxide on Photosynthesis, Plant Growth and other Processes. In *Impact of Carbon Dioxide, Trace Gases, and Climate Change on Global Agriculture*. ASA Special Publication No. 53. American Society of Agronomy, p:45-60.

Gates, W.L., P.R. Rowntree, and Q-C. Zeng. 1990. Validation of Climate Models. In J.T. Houghton, G.J. Jenkins, and J.J. Ephraums (eds.). 1990. *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press, New York.

Hulme, M., Wigley, T.M.L., Barrow, E.M., Raper, S.C.B., Cantella, A., Smith, S., and Chipanshi, A. 2000. *Using Climate Scenario Generator in Vulnerability and Adaptation Assessments: MAGICC and SCENGEN Version 2.4.* Workbook. National Communication Support Program. Climate Research Unit, Norwich, UK, 68pp.

IPCC, 1996. *Climate Change 1995: Impact, Adaptation and Mitigation of Climate Change: Scientific-Technical Analyses*. Contribution of Working Group II to the Second Assessment Report of the IPCC. Cambridge University Press, Cambridge, UK and NY. 880p.

IPCC. 2000. *IPCC Special Report on Emission Scenarios*. Cambridge University Press, Cambridge, UK.

Raper, S.C.B., Warrick, R.A., and Wigley, T.M.L. 1996. Global Sea Level Rise: Past and Future. Pp:11-145 in *Sea Level Rise and Coastal Subsidence: Causes, Consequences and Strategies* [Milliman, J.D., and Haq, B.U. (eds)]. Kluwer Academic Publishers, Dordrecht, Germany, 369pp.

Ratag, M.A., Asiati, S., Nuryanto, A, Siswanto, B and Suyadhi. 1998. Greenhouse Gases, Climate Change and El-Nino. In *Economic Assessment of Greenhouse Gas Abatement Options*. ALGAS Final National Workshop.

Trenberth, KE and Houghton, JT, 1996. *The 1990-1995 El Nino-Southern Oscillation Event: Longest on Record*. Geographical Research Letter 23: 57-60.

Trenberth, KE and Houghton, JT, 1996. *The Climate System*, and Maskell, K(eds) *Climate Change 1995: The Science of Climate Change*. Cambridge University Press, pp 51-64.

II. IMPACT OF CLIMATE CHANGE ON CAMBODIA'S CLIMATE

II.1. Introduction

Cambodia's climate is governed by monsoons and characterized by two major seasons: from mid-May to early October, strong prevailing winds from the southwest bring heavy rains and high humidity and from early November to mid-March, winds and humidity are low. Between these two seasons is a transitional period. The average annual rainfall is 1,400 mm in the central low land regions and may reach 5,000 mm in certain coastal zones or in highland areas. The annual average temperature is 28^{o}C, with a maximum average of 38^{o}C in April, and a minimum average of 17^{o}C in January.

The coastal zone of Cambodia experiences high relative humidity with mean annual relative humidity values ranging around 85%. Minimum average humidity is recorded in December and January, while maximum relative humidity occurs in August through October. Wind speed in the coastal areas ranges from 2 to 4 m/s. Strong offshore winds of 16m/s have been recorded and almost every year Cambodia's coastal zone is affected by tropical cyclones from the Pacific Ocean. However, the country is rarely exposed to the full force of typhoon because it is surrounded by mountain chains which dissipate the force of the typhoon. Storms occur more frequently during the period from August to November, with the highest frequency in October.

The occurrence of drought and floods is common in the country. Floods are associated with typhoons and heavy rains throughout the Mekong basin, which often occur from May to September, while quite severe drought is associated with El-Nino events. As of to date no detailed studies on the effect of El-Nino and La-Nina (ENSO Phenomena) as well as studies related to the impact of global warming on Cambodia's climate have been conducted.

The objectives of this study are:

- To review Cambodia's climate in particular rainfall;
- To evaluate Cambodia's rainfalls during ENSO events;
- To evaluate the performance of two General Circulation Models (GCMs) in Cambodia; and
- To evaluate the impact of global climate change under two IPCC emission scenarios on Cambodia climate using the two GCMs.

II.2. Cambodia's Climate

Meteorological Stations. The number of operating rainfall stations in Cambodia is limited. Before the civil war (before 1970) the number of rainfall stations in Cambodia was 61. At present the number of operating stations has decreased dramatically to 12 stations for the whole country. Similarly, air temperature is only recorded in a few locations. Before 1979, there were12 stations and now there are just 6 stations. There is only one station that records other climatic variables (evaporation, radiation, wind etc.). A list of the stations is presented in Appendix 2.7.1.

Climate. Cambodia's climate is governed by monsoons and characterized by two major seasons, wet season and dry season. Wet season is between mid May to early October, while dry season is between November to mid May. Annual rainfall varies considerably across the country. In the low land areas annual rainfall ranges from 1,000 to 1,700 mm while in the highland it ranges from 1,000 to 2,700 mm and in the coastal areas -- from 1,000 to 3,000 mm. As detailed maps showing the division of Cambodia according to its rainfall patterns do not exist, an analysis to divide Cambodia into several homogenous rainfall patterns was performed in this study. The analysis was carried out using Principal Component Analysis (PCA) and Cluster Analysis (CA). Statistical explanation of PCA and CA analysis can be found in many statistical books (e.g. Krzanowski, 1988). The procedure for dividing the regions into several homogenous rainfall pattern regions followed the procedure described in Boer *et al.*, (1993a, 1993b). The result of this analysis indicated that Cambodia could be divided into eight homogenous rainfall regions (Figure 2.1). Rainfall patterns I, II and III cover the largest area and followed by pattern V, VII, VIII and VI. Region I, II and III are all in low land areas, while rainfall regions V to VIII are mostly in the high land and coastal areas.

Stations, which record air temperature data, are all in lowland areas with elevations of between 0 and 170 m. Monthly minimum temperatures in these stations ranged from 19.6 to 26.6^{o}C and maximum temperatures between 29.5 and 35.9^{o}C. Highland temperature records do not exist. Since temperature is highly correlated with elevation of location (Boer et al., 1999; Ravindranath and Deshingkar, 1997), temperature in these areas could be estimated. A study in India showed that mean annual temperature (t) could be estimated using the following equation: t = 28.72 - 0.00643 Alt, where Alt is the altitude of a location. In Indonesia the equation was developed for each month (Boer *et al.*, 1999). It was indicated that the mean monthly maximum temperature decreased between 0.60 and 0.71^{o}C for every 100 m increase in elevation, while minimum temperature decreased between 0.54 and 0.60^{o}C. The mean annual maximum (t_{max}) and minimum temperature (t_{min}) could be estimated using the following equation (Boer *et al.*, 1999):

$$t_{max} = 31.675 - 0.00635*Alt;$$

and

$$t_{min} = 23.112 - 0.00573*Alt.$$

These two equations are adopted for use to estimate mean annual temperature of any location in Cambodia based on its altitude. In order to obtain mean annual maximum and minimum temperatures, the deviations of observed mean monthly maximum and minimum temperature of existing stations (Appendix 2.7.1) from their annual mean were used to adjust the two equations for Cambodia. The two equations for Cambodia are the following:

$$T_{max} = 32.015 - 0.00635*Alt;$$

and

$$T_{min} = 23.602 - 0.00573*Alt.$$

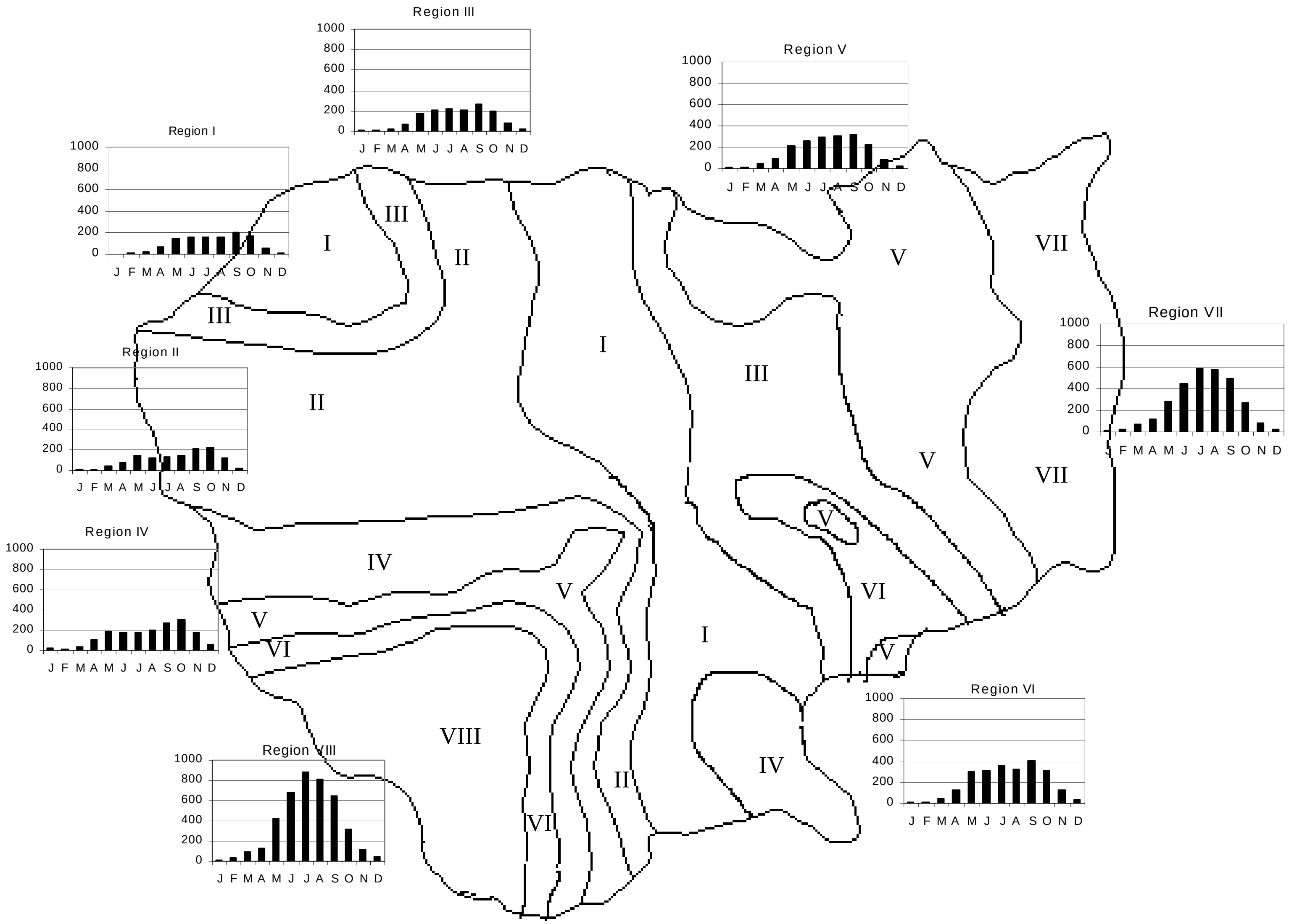


Figure 2.1: Division of Cambodia According to its Rainfall Pattern

Coefficient of variation (CV) of the monthly rainfall was closely related with its amount. The CV decreased exponentially with rainfall amount and then remains constant when rainfall amount is greater than 210 mm (Figure 2.2). For temperature, the CV was relatively constant.

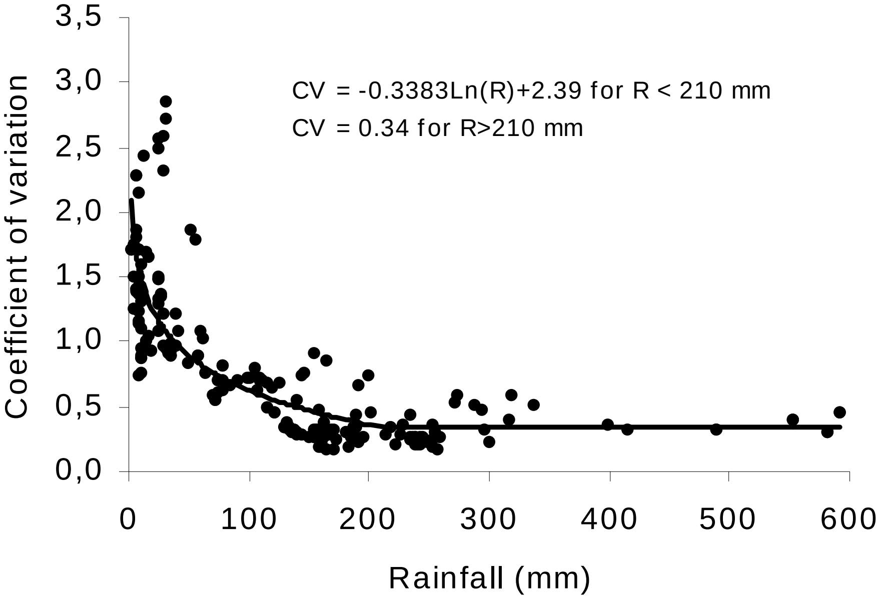


Figure 2.2: Relationship between CV and Rainfall Amount

Furthermore, the effect of ENSO (in this discussion it refers to El-Nino and La-Nina) on Cambodia's rainfall is not consistent (Table 2.1; rainfall anomaly in ENSO years for wet season and dry season in each rainfall regions is presented in Appendix 2.7.2). In general in the low land regions, the impact of El-Nino on wet and dry season rainfall was negative while the impact of La-Nina was positive. In the upland and coastal regions, the impact of El-Nino on wet season rainfall for some months was positive and some were relatively normal, while on dry season rainfall, the impacts were commonly negative. In La-Nina years, most of the monthly rainfall in both seasons increased above normal. However, this pattern was more consistent in the low land regions than in the coastal or upland regions. In the coastal and upland regions in some La-Nina years, rainfall decreased below normal. This inconsistency is due to the presence of local effects on rainfall. The upland and coastal regions are mostly situated in mountainous regions where the topographic effect is strong. In addition, along the coast and upland, a sea breeze effect also exists. Another important factor that affects the rainfall in Cambodia is the monsoon system.

**Table 2.1: Impact of ENSO Events on Wet Season (May-Oct.)
and Dry Season Rainfall (Nov.-Apr.)**

Location	EN		LN		Note
	WS	DS	WS	DS	
Coastal	+/0	-	-/+	+/0	Based on Kampong Som and Kampot rainfall stations
Low land	-/0	-	-/+	+	Based on Pochentong station
High land	0/+	-/0	0/+	+/0	Based on Kratie station

Note: + and - represent positive and negative impact, while 0 -- no impact.

II.3. Verification of GCM Models

Emission Scenarios. As previously mentioned, GHG emissions in the future may increase at a slow rate or at a high rate depending on driving forces such as demographic development, socio-economic development, and technological change (IPCC, 2000). Implementation of climate policy or GHG emission targets by developed countries as stated in the Kyoto Protocol may also affect the rate of the GHG emissions. The Intergovernmental Panel on Climate Change (IPCC) has developed scenarios of future GHG emissions using several assumptions of the driving forces. The scenarios provide alternative images of how the future might unfold and are an appropriate tool with which to analyze how the driving forces may influence future emission outcomes and to assess associated uncertainties. Impacts of increasing GHG concentrations in the atmosphere on global and regional climate is evaluated by General Circulation Models (GCMs).

Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) includes six IS92 scenarios: IS92a up to IS92f, and four SRES scenarios: SRESA1, SRESA2, SRESB1 and SRESB2. In this analysis new IPCC scenarios were used, SRESA2 and SRESB1. These two scenarios were selected as they reflect current understanding and knowledge about underlying uncertainties in the emissions. SRESA2 describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slow. SRESB1 describes a convergent world with the same global population that peaks in mid-century and declines thereafter, rapid change in economic structures toward a service and information economy, with reduction in material intensity, and the introduction of clean and resource-efficient technology (IPCC, 2000). With these characteristics, the SRESA2 will lead to higher future GHG emissions while SRESB1 leads to lower future GHG emissions. Thus SRESB1 was defined as a policy scenario, while SRESA2 as a reference scenario.

For assessing the impact of global warming on Cambodia's Climate, two GCM models were selected. The first is a GCM developed by Australia (for southern hemisphere) and the second one -- by Japan (for northern hemisphere). In the analysis, model parameters in MAGICC (i.e. carbon cycle, aerosol forcing, climate sensitivity) were set as default values (mid range values). The default values for these parameters are:

- Carbon cycle parameters (Dn80s) = 1.1 GtC (Schimel *et al.*, 1995);

- Aerosol forcing = -0.30 W m^{-2} for direct clear-sky effect of sulphate aerosols from fossil fuel combustion and -0.80 W m^{-2} for indirect effect of aerosol-induced changes in cloud albedo (Kattenberg *et al.*, 1996);
- Climate sensitivity (increased in global temperature under doubling CO_2 concentration in the atmosphere, ΔT_{2x}) = 2.5°C.

Future Environmental Conditions under SRESA2 and SRESB1 Scenarios. Based on the two scenarios described above, in the next 100 years, concentrations of CO_2 in the atmosphere under the reference emission scenario would be more than double, while under the policy emission scenario only 1.5 times the current condition. Similarly for other gases (CH_4 and N_2O; Table 2.2). Concentration of SO_2, which counters the effect of greenhouse gases, would not change significantly (Table 2.3).

Table 2.2: Gas Concentrations (ppmv)

Year	2000	2025	2050	2100
CO_2:				
SRESA2: Best guess	370	440	535	825
: Range	370	430-450	515-555	760-890
SRESB1: Best guess	370	420	460	550
: Range	370	410-430	450-470	510-590
CH_4:				
SRESA2: Best guess	1600	2250	2850	4300
: Range	1600	2200-2300	2700-3000	3800-4800
SRESB1: Best guess	1600	2050	2250	2200
: Range	1600	2000-2100	2150-2350	2100-2300
N_2O:				
SRESA2: Best guess	316	344	375	452
SRESB1: Best guess	316	340	360	395

Table 2.3: Gas Emissions: SO_2 (Sulphur Dioxide Emissions) (Tg S)

Year	2000	2025	2050	2100
Global:				
SRESA2	70	110	108	63
SRESB1	70	58	55	32
Asia:				
SRESA2	30	62	57	28
SRESB1	30	30	25	11

Under increased GHG conditions, it was estimated that global temperature will consistently increase by about 0.027°C per year, while sea level increased by about 0.6 cm per year (Table 2.4). Historical records show that over the last 100 years the global sea level has increased between 0.10-0.25 cm per year (Warrick *et al.*, 1996; Douglas, 1995; Gornitz, 1995).

Table 2.4: Temperature (^{o}C) and Sea Level Rise (cm), w.r.t. 1990

Year	2000	2025	2050	2100
Temperature: SRESA2: Best guess	0.2	0.5	1.2	2.9
: Range	0.15-0.25	0.3-0.7	0.8-1.6	2.0-4.1
SRESB1: Best guess	0.2	0.7	1.1	1.9
: Range	0.15-0.25	0.5-0.9	0.7-1.6	1.2-2.7
Sea Level: SRESA2: Best guess	2	10	21	60
: Range	0-4.0	4.0-20	9.0-41	25-112
SRESB1: Best guess	2	10	21	48
: Range	0-4.0	4.0-22	9.0-42	18-85

Verification of GCM Models. To verify GCM output under current climate condition, a model called a global and regional SCENario GENerator (SCENGEN) was run using the following control menu: Climate Sensitivity set at mid (2.5^{o}C), Time Interval (under **Edit** menu) at 1961-1990 baseline. This selection was made in order to compare GCM output under current CO_2 concentrations with observation data (61 stations with data records between 1907 to 2000; Appendix 2.7.1), and to develop a correction factor for the future climate data under the two scenarios (GCM's output for the 30-year period centered on 2025, 2050 and 2100). The analysis was carried out in several steps.

The first step of the analysis was to interpolate observed monthly rainfall into grid of GCM models using Kriging technique. In this study the GCM model used was CCSR (developed in Japan) and CSIRO (developed in Australia). The second step involved running the MAGIC-SCENGEN under current or baseline conditions (1960-1990) and then extracting the rainfall data from the model. The third step required calculating the deviation of GCM outputs from the interpolated observed rainfall data. The deviation values were used as correction factors for future climate conditions taken from SCENGEN (GCM outputs for 2025, 2050 and 2100) for the two different scenarios. In this study, it was assumed that deviations of GCM outputs in the future would remain the same. These corrected GCM outputs were then used in the subsequent analysis, i.e. assessment of the vulnerability of agriculture and forestry to climate change (Chapter III and IV).

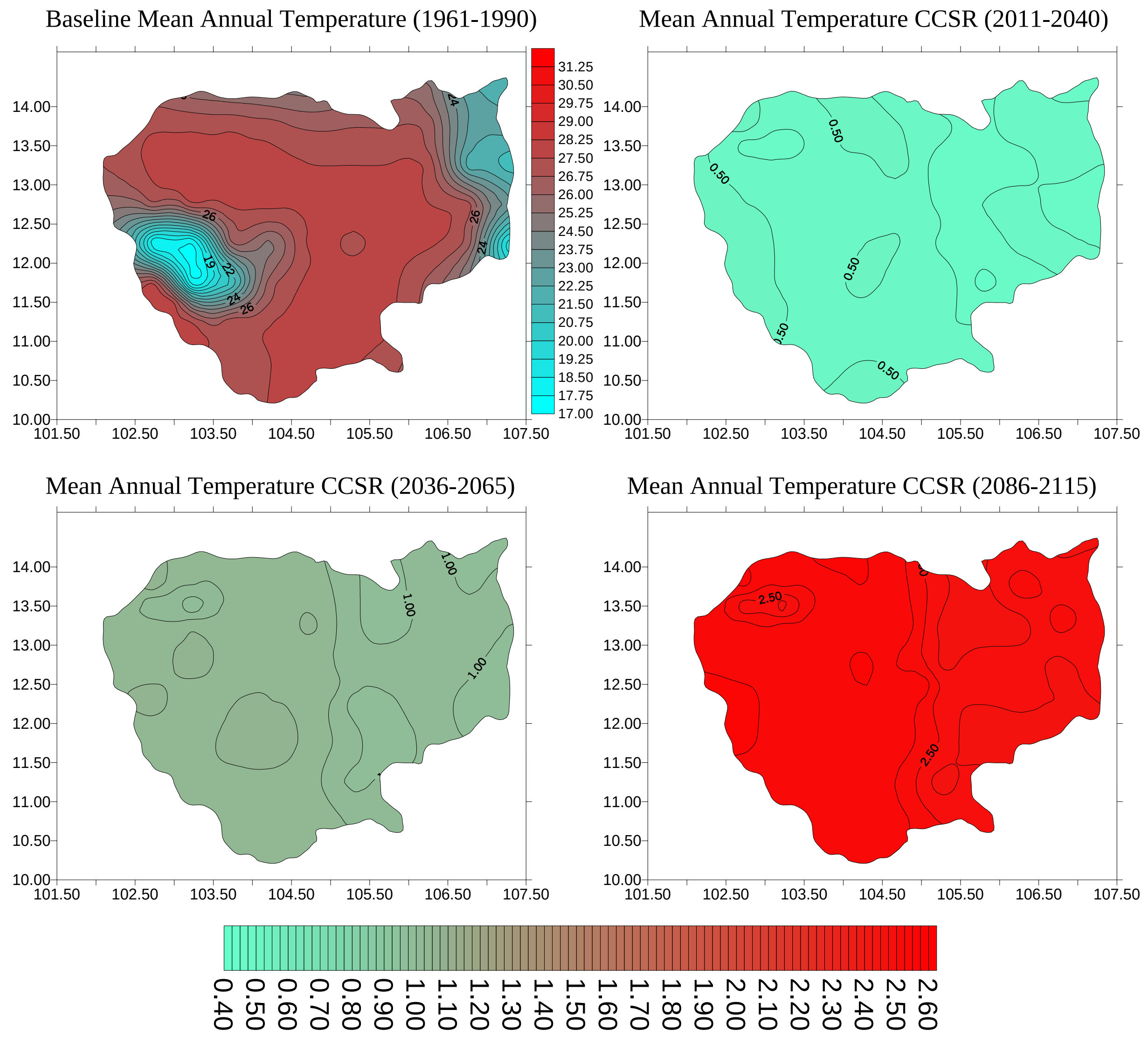
II.4. Impact of Climate Change on Cambodia's Climate

From the analysis, it was found that the GCM outputs were consistently higher than the observed (Appendix 2.7.3). The mean deviation between observed rainfall and GCM outputs in the eight rainfall regions ranged from 16 to 794 mm. The deviations increased considerably in the wet season while decreasing in the dry season. In the subsequent analysis, all outputs from GCM for future years (2025, 2050 and 2100) were corrected using the deviation values.

Temperature. The two GCM models suggested that temperature in Cambodia would increase due to the increase in CO_2 concentrations. However the increase in temperature between the two models was not the same. Under scenario SRESA2, the CCSR model suggested that the mean annual temperature would increase to about 0.60^{o}C in 2025 and it will further increase to about 1.00^{o}C and 2.50^{o}C in 2050 and 2100 respectively (Figure 2.3). The CSIRO model suggested that the increase in temperature from the current year's temperature in 2025, 2050 and 2100 would be about 0.30, 0.70 and 2.00°C respectively (Figure 2.4). Similarly under SRESB1 scenario, the increase in mean annual temperature from the current temperature in 2025, 2050 and 2100 using CCSR would be about 0.60, 0.90 and 1.60°C respectively and using CSIRO would be about 0.45, 0.75 and 1.35°C respectively (Figure 2.5 and 2.6).

Rainfall. Similar to temperature, the changes in rainfall under the two emission scenarios estimated by CCSR is different from those estimated by CSIRO. Using CCSR under SRESA2, annual rainfall in Cambodia would increase by up to 6% of the current rainfall with the magnitude of change varying with time and location. In 2025, the increase in rainfall in the lowland areas would be higher than that in the high land and coastal areas. Percentage increase in rainfall for the lowland areas is likely to be between 4 and 8% while in the high land and coastal areas --between 0 and 4%. In 2050, the predicted percentage changes in rainfall for the low land, high land and coastal areas are higher than those occurring in 2025. In the low land areas the change in rainfall would be between 8 and 12% while in the high land and coastal areas --between 2 and 6% (Figure 2.7). In 2100, the change in rainfall would be lower than would occur in 2025 and 2050. The CCSR model suggests that under elevated CO_2, Cambodia's rainfall would increase from the baseline up to year 2050 and then decrease again in 2100. Using CSIRO, rainfall would continuously increase from baseline until 2100. The increase in rainfall from baseline for 2025, 2050 and 2100 would be between 5 and 15%, between 5 and 23% and between 3-35% respectively (Figure 2.8). Similar patterns were also observed for SRESB1, however, the magnitude of changes are smaller than those of SRESA2 (Figure 2.9 and 2.10). Maps showing isohyets of dry season and wet season rainfalls under current and future climate are presented in Appendix 2.7.4.

In this study, all GCM outputs are based on monthly periods. In some cases, daily data is required to perform vulnerability and adaptation assessments. Therefore, for further study, techniques to generate daily climatic data from monthly data should be explored and assessed. This will facilitate the country to use more sophisticated methods requiring daily inputs.



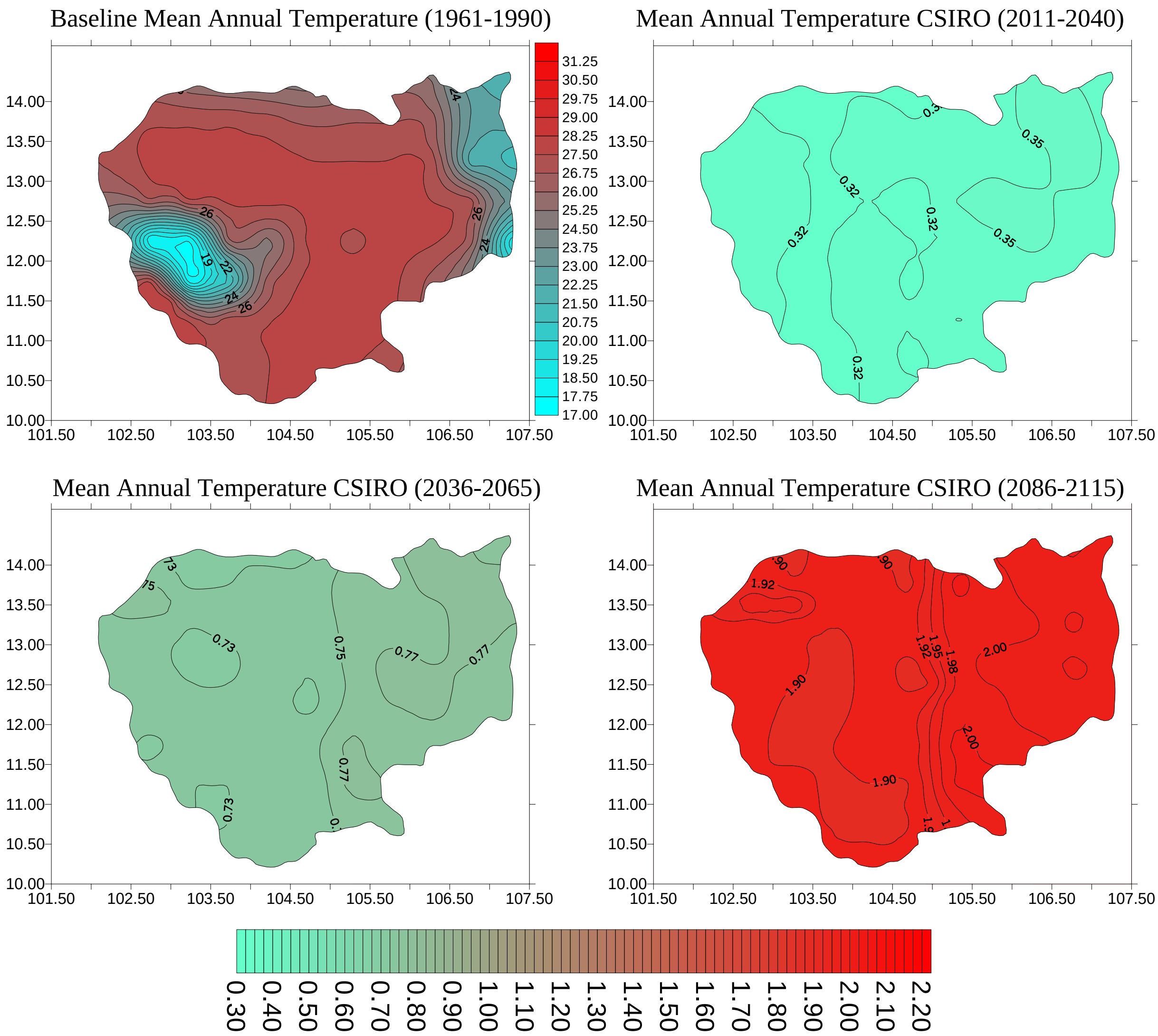
Baseline Mean Annual Temperature (1961-1990)

Mean Annual Temperature CCSR (2011-2040)

Mean Annual Temperature CCSR (2036-2065)

Mean Annual Temperature CCSR (2086-2115)

Figure 2.3: Mean Annual Temperature at Current Conditions (Mean of 1961-1990), and Degree Change of Mean Annual Temperature for 2025 (Mean of 2011-2040), 2050 (Mean of 2036-2065) and 2100 (Mean of 2086-2115) Using CCSR GCM Model and Emission Scenario of SRESA2



Baseline Mean Annual Temperature (1961-1990)

Mean Annual Temperature CSIRO (2011-2040)

Mean Annual Temperature CSIRO (2036-2065)

Mean Annual Temperature CSIRO (2086-2115)

Figure 2.4: Mean Annual Temperature at Current Conditions (Mean of 1961-1990), and Degree Change of Mean Annual Temperature for 2025 (Mean of 2011-2040), 2050 (Mean of 2036-2065) and 2100 (Mean of 2086-2115) Using CSIRO GCM Model and Emission Scenario of SRESA2

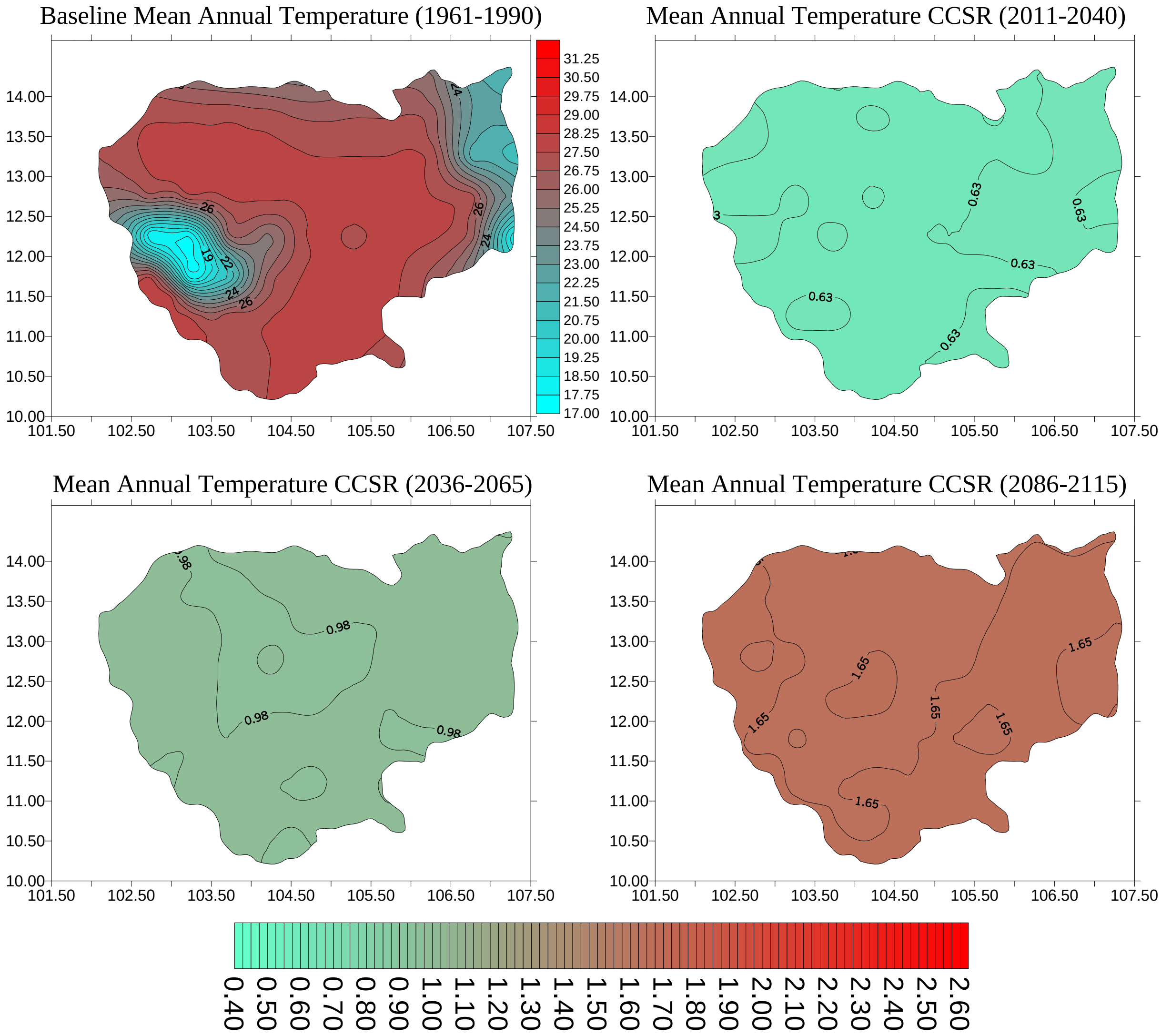
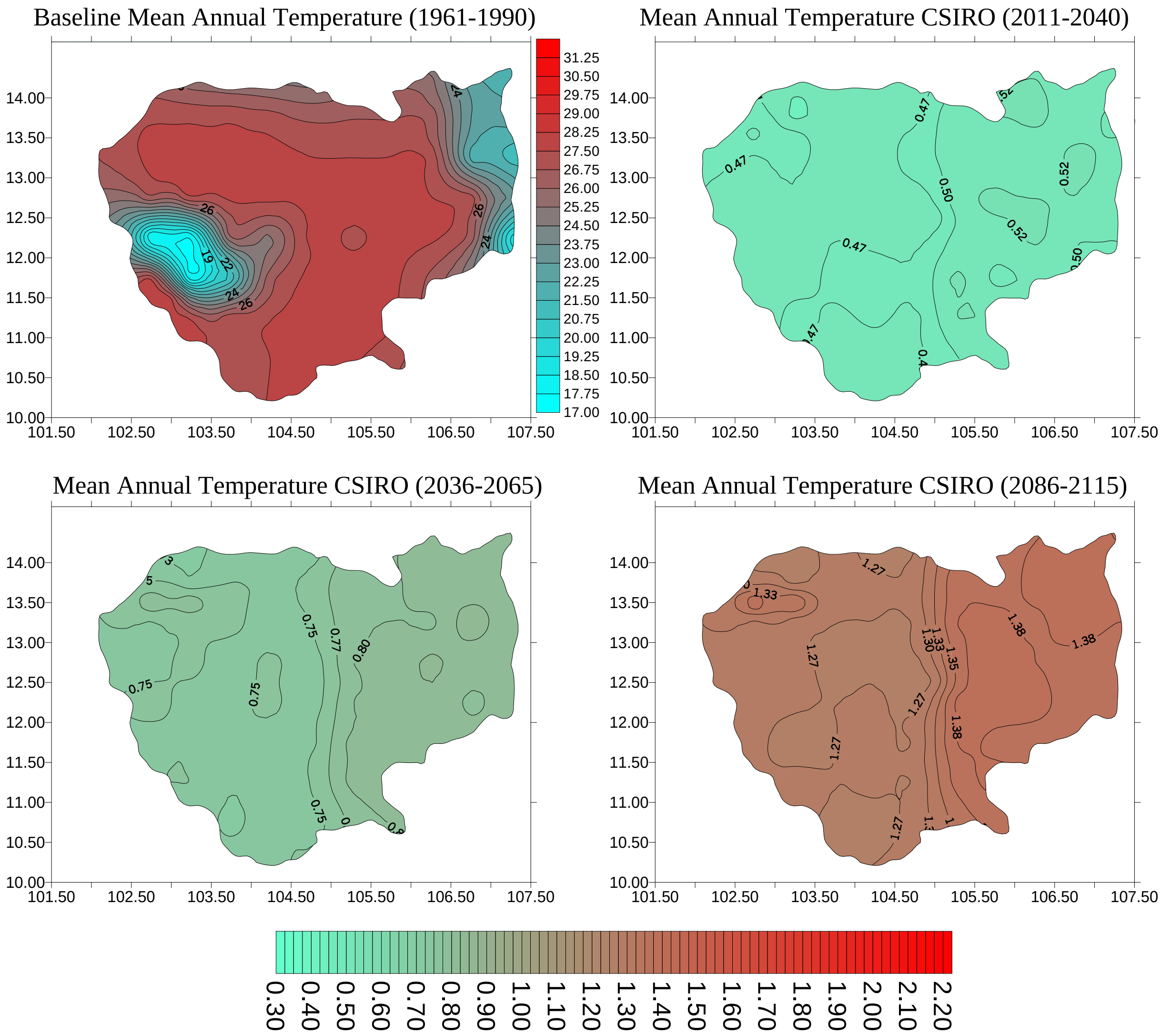


Figure 2.5: Mean Annual Temperature at Current Conditions (Mean of 1961-1990), and Degree Change of Mean Annual Temperature for 2025 (Mean of 2011-2040), 2050 (Mean of 2036-2065) and 2100 (Mean of 2086-2115) Using CCSR GCM Model and Emission Scenario of SRESB1



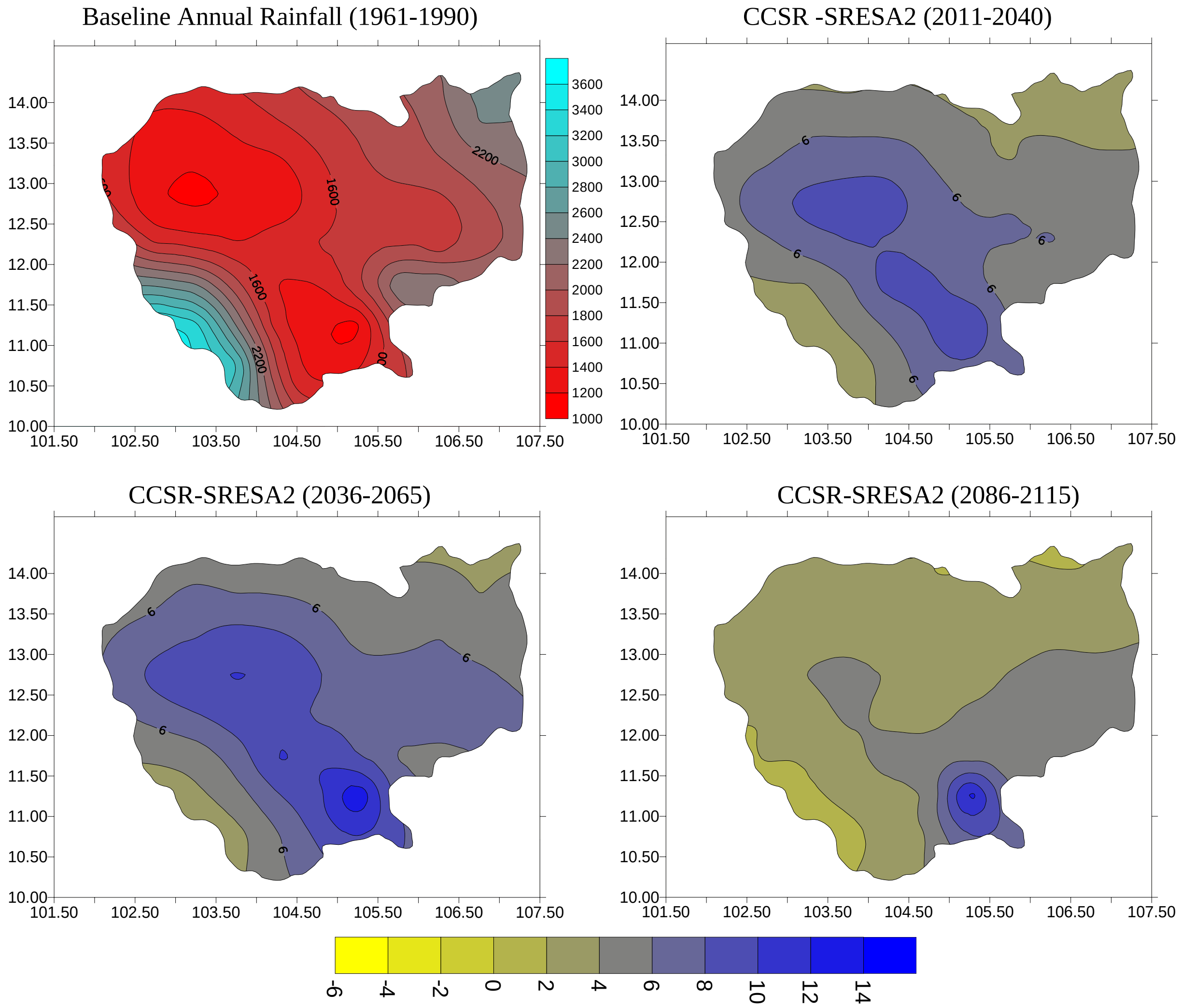
Baseline Mean Annual Temperature (1961-1990)

Mean Annual Temperature CSIRO (2011-2040)

Mean Annual Temperature CSIRO (2036-2065)

Mean Annual Temperature CSIRO (2086-2115)

Figure 2.6: Mean Annual Temperature at Current Conditions (Mean of 1961-1990), and Degree Change of Mean Annual Temperature for 2025 (Mean of 2011-2040), 2050 (Mean of 2036-2065) and 2100 (Mean of 2086-2115) Using CSIRO GCM Model and Emission Scenario of SRESB1



Baseline Annual Rainfall (1961-1990)

CCSR -SRESA2 (2011-2040)

CCSR-SRESA2 (2036-2065)

CCSR-SRESA2 (2086-2115)

Figure 2.7: Annual Rainfall at Current Conditions (Mean of 1961-1990), and Percent Change of Annual Rainfall for 2025 (Mean of 2011-2040), 2050 (Mean of 2036-2065) and 2100 (Mean of 2086-2115) Using CCSR GCM Model and Emission Scenario of SRESA2

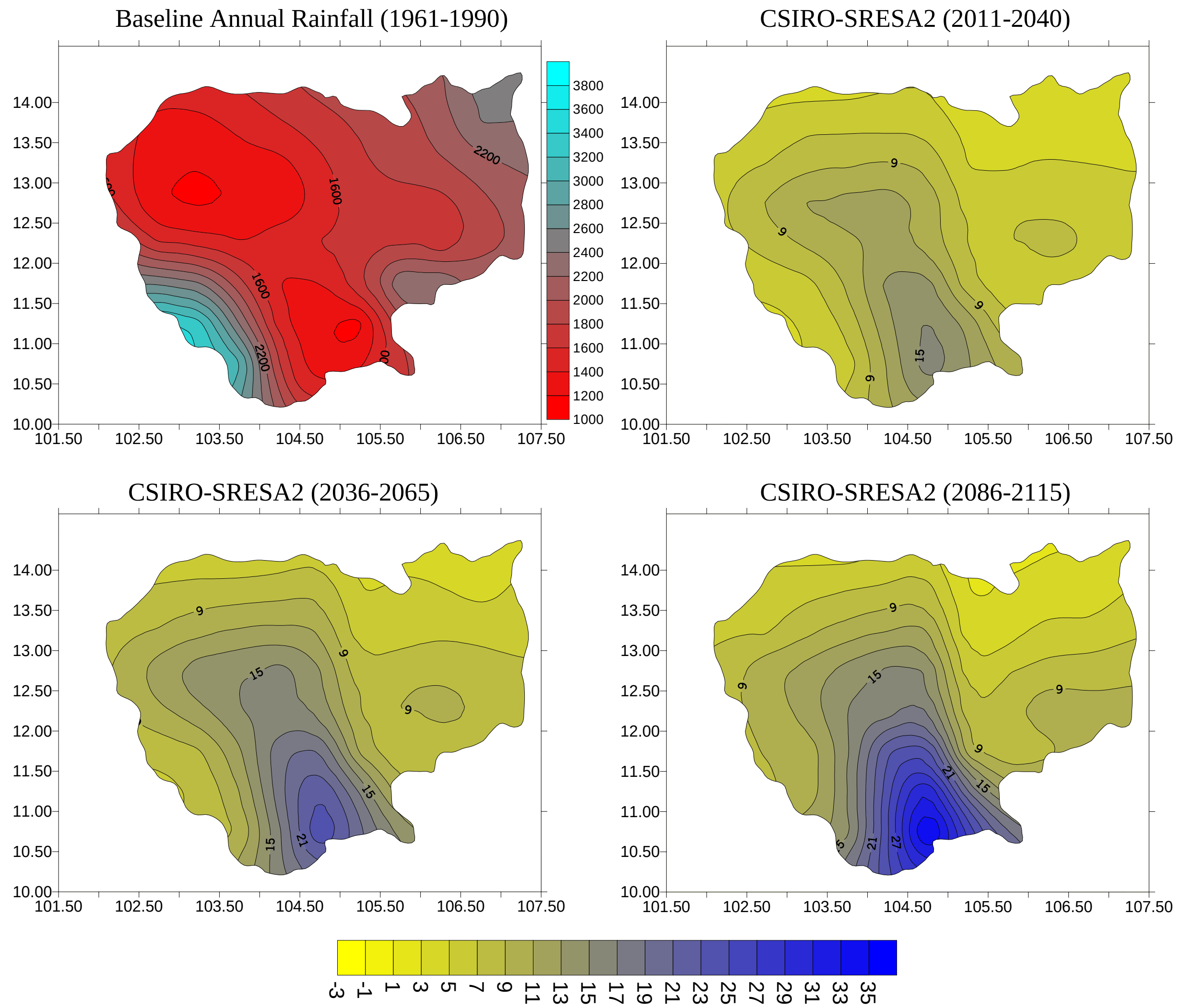
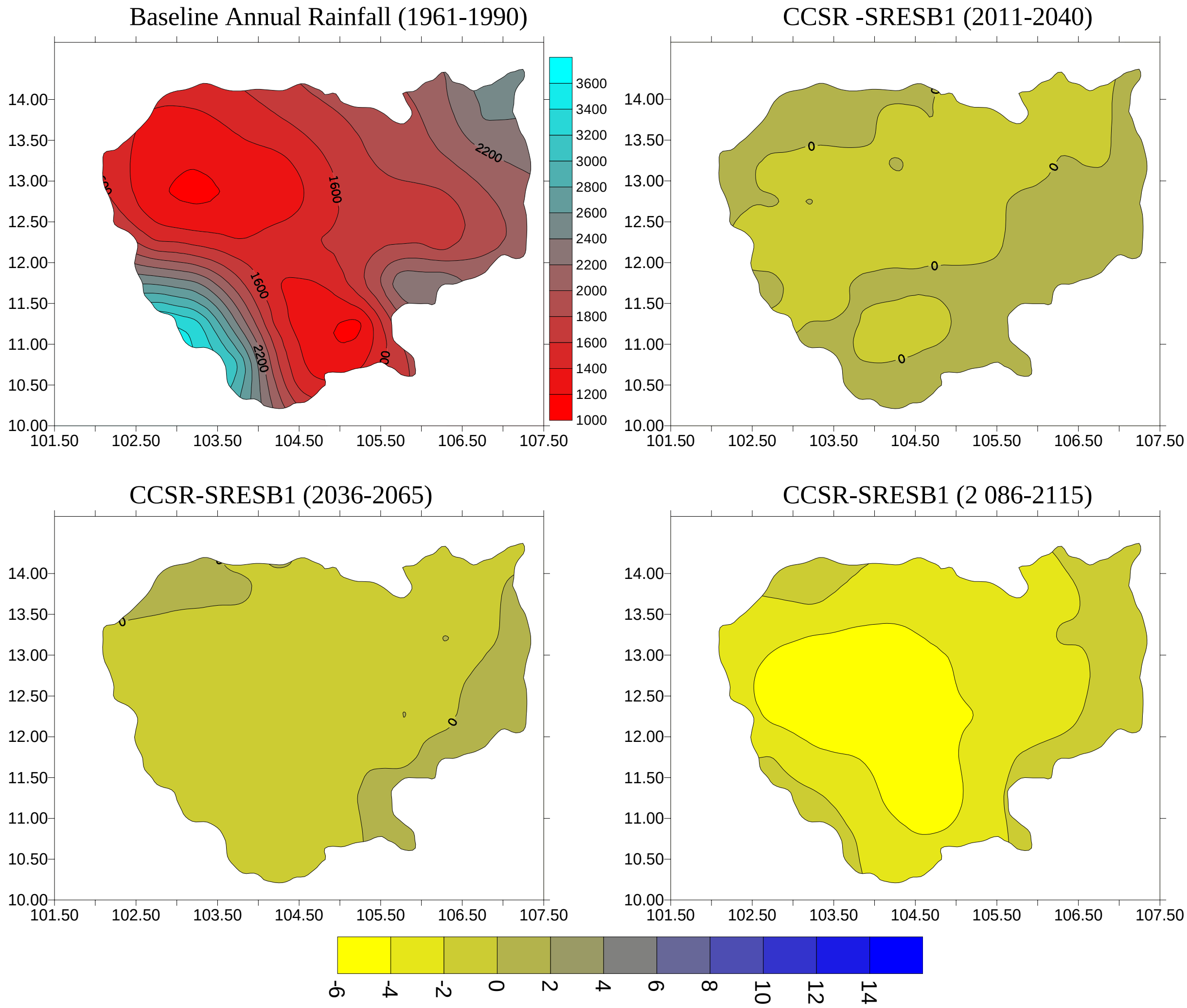


Figure 2.8: Annual Rainfall at Current Conditions (Mean of 1961-1990), and Percent Change of Annual Rainfall for 2025 (Mean of 2011-2040), 2050 (Mean of 2036-2065) and 2100 (Mean of 2086-2115) Using CSIRO GCM Model and Emission Scenario of SRESA2



Baseline Annual Rainfall (1961-1990)

CCSR -SRESB1 (2011-2040)

CCSR-SRESB1 (2036-2065)

CCSR-SRESB1 (2 086-2115)

Figure 2.9: Annual Rainfall at Current Conditions (Mean of 1961-1990), and Percent Change of Annual Rainfall for 2025 (Mean of 2011-2040), 2050 (Mean of 2036-2065) and 2100 (Mean of 2086-2115) Using CCSR GCM Model and Emission Scenario of SRESB1

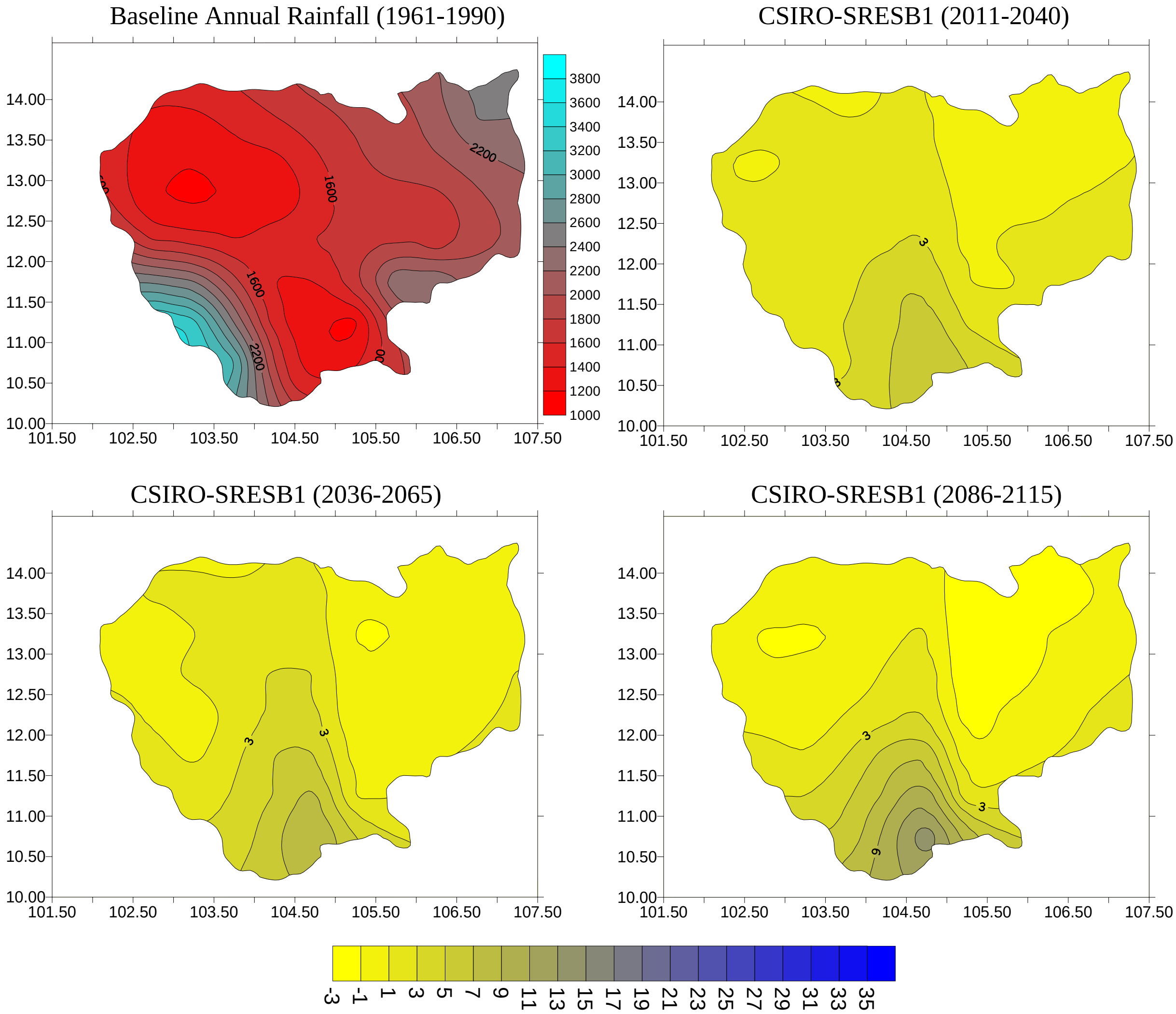


Figure 2.10: Annual Rainfall at Current Conditions (Mean of 1961-1990), and Percent Change of Annual Rainfall for 2025 (Mean of 2011-2040), 2050 (Mean of 2036-2065) and 2100 (Mean of 2086-2115) Using CSIRO GCM Model and Emission Scenario of SRESB1

II.5. Conclusion and Recommendations

GCM models used in this analysis (CCSR and CSIRO) were not very suitable for use in Cambodia because the two models were developed for use Japan and Australia which are very different geographical region. The deviation of GCM models from the observed rainfall data was very significant. The deviation of monthly wet season rainfall from the observed rainfall could reach 794 mm.

Under SRESA2 scenario, temperature in Cambodia would increase by up to 2.0°C using CSIRO and up to 2.5°C using CCSR model. Under SRESB1, the increase was smaller, i.e. 1.35°C under CSIRO and 1.60°C under SSCR.

Rainfall in Cambodia would also increase from the current conditions. The magnitude of the increase would also vary with location, time, GCM models and emission scenario. Low land areas would be more affected than high land areas according to the models. Under SRESA2, annual rainfall in 2100 would increase between 3 and 35% from the current rainfall depending on location, while under SRESB1 the increase would be smaller.

II.6. REFERENCES

Boer, R., Campbell, L.C. and Fletcher, D.J. 1993. *Characteristics of Frost in a Major Wheat Growing Region of Australia*. Australian Journal of Agricultural Research (44):1751-1743.

Boer, R., Fletcher, D.J., and Campbell. L.C. 1993. *Rainfall Pattern in a Major Wheat Growing Region of Australia*. Australian Journal of Agricultural Research (44):609-624.

Boer, R., Las, I., dan Notodiputro, K.A. 1999. Analisis risiko kekeringan untuk pengembangan dan produksi kedelai di Flores Nusa Tenggara Timur (*Climatic Risk Analysis for Soybean Production at Flores, East Nusa Tenggara*). Kantor Menteri Negara Riset dan Teknologi, Dewan Riset Nasional. Laporan RUT-IV.

IPCC, 2000. *IPCC Special Report on Emissions Scenarios: Summary for Policymakers*. Intergovernmental Panel on Climate Change, World Meteorological Organization and Unite Nations Environment Program, 20pp.

Kattenberg, A., Giorgi, F., Grassl, H., Meehl, G.A., Mitchell, J.F.B., Stouffer, R.J., Tokioka, T., Weaver, A.J., and Wigley, T.M.L. 1996. Climate Models - Projections of Future Climate. Pp:285-357 in *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios* [Haoughton, J.T., Meiro Filho, L.G., Callender, B.A., Kattenburg, A and Maskell, K. (eds)]. Cambridge University Press, UK, 572pp.

Krzanowski, W.J. 1988. *Principles of Multivariate Analysis*. A user's perspective. Cleredon Press. Oxford. pp:53-83.

National Communications Support Programme. 2000. *Using a Climate Scenario Generator in Vulnerability and Adaptation Assessments: MAGICC and SCENGEN Version 2.4 Workbook*. National Communications Support Programme, 62pp.

Raper, S.C.B., Warrick, R.A., and Wigley, T.M.L. 1996. Global Sea Level Rise: Past and Future. Pp:11-45 in *Sea Level Rise and Coastal Subsidence: Causes, Consequences and Strategies* (Milliman, J.D. and Haq, B.U. eds), Kluwer Academic Publishers, Dordrecht, Germany, 369pp.

Ravindranath, N.H., and Deshingkar, P. 1997. *Climate Change and Forests: Impact and Adaptation: A Regional Assessment for the Western Ghats, India*. Atmospheric Environment Issues in Developing Countries Series-No. 4. Stockholm Environment Institute, 93p.

Schimel, D., Enting, I.G., Heimann, M., Wigley, T.M.L., Raynaud, D., Alves, D., and Siegenthaler, U. 1995. CO_2 and the Carbon Cycle. Pp:35-71 in *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios* [Haoughton, J.T., Meiro Filho, L.G., Callender, B.A., Kattenburg, A and Maskell, K. (eds)]. Cambridge University Press, UK, 572pp.

Warrick, RA., Provost, C., Merier, M.F. Oerlemans, F., and Woodworth, P.L. 1996. Change in Sea Level. In *Climate Change 1995: The Science of Climate Change*. Contribution of Working Group I to the IPCC Second Assessment Report. Cambridge University Press, United Kingdom .

II.7. APPENDIX

Appendix 2.7.1: Rainfall Station Used in the Analysis

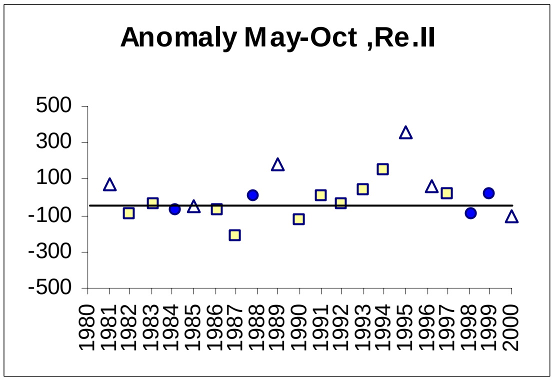
No	Stations Name	Lat. (N)	Long.	Alt. (m)	Period of Record, yr	
					Rainfall	Temperature
1	**Pochentong**	11.33	104.55	10	77	72
2	**Takmau, Kandal**	11.25	104.55	n/a	13	
3	**Krakor, Pursat**	12.32	104.11	12	53	
4	Pursat	12.33	103.50	18	48	5
5	Bamnak	12.18	104.10	10	11	
6	Boribo	12.27	104.22	11	3	
7	**Battambang**	13.11	103.12	22	73	35
8	Pailin	12.49	102.37	170	24	
9	Reangkesei	12.58	103.14	15	4	
10	Maung Russei	12.47	103.25	17	22	
11	Leach	12.21	103.41	n/a	23	
12	**Kampong Thom**	12.42	104.52	13	59	
13	Baray	12.23	105.04	12	47	
14	Staung	12.57	104.33	12	27	
15	Kampong Khleng	13.06	104.07	10	28	
16	**Kampong Som**	10.38	103.29	13	26	19
17	**Kampot**	10.36	104.11	5	75	9
18	Bokor	10.36	104.02	1050	22	
19	Kep	10.29	104.18	2	31	
20	Kampong Trach, K.	10.33	104.28	4	47	
21	Chhuk	11.07	104.37	20	13	
22	Tani	11.07	104.39	20	33	
23	**Kratie, Sambor**	12.46	105.58	29	47	
24	Rokar Kandal	12.29	106.10	23	10	
25	Chlong	12.16	105.58	20	30	
26	Prek Chlong	11.52	106.15	210	29	
27	Snoul	12.07	106.07	150	30	
28	**Takeo**	11.00	104.47	5	64	
29	Bat Rokar	11.09	104.53	8	4	
30	Angtassom	11.00	104.41	12	32	
31	Kirivong	10.41	104.53	7	46	
32	**Stung Treng**	13.31	105.58	51	68	28
33	**Siem Reap**	13.22	103.12	21	63	42
34	Samrong	14.13	103.33	22	18	
35	Baray Dangkor	13.25	103.51	20	10	
36	Kralanh	13.33	103.23	17	20	
37	**Svay Rieng**	11.05	105.48	6	67	24
38	Soc Noc	10.59	106.08	5	23	
39	Kampong Trach, Sv.	11.28	105.45	4	12	
40	Chipou	11.02	106.01	5	10	
41	Kampong Rau	10.55	105.56	n/a	6	

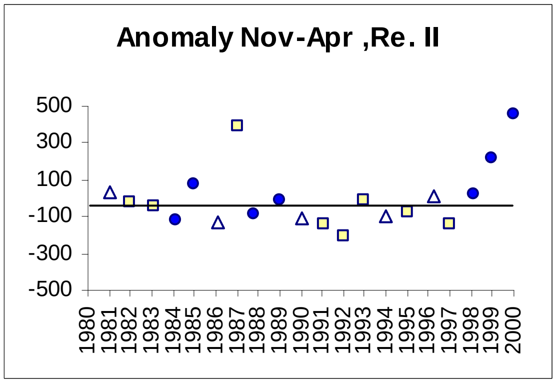
Appendix 2.7.1 (cont.)

42	**Kampong Cham**	12.00	105.27	19	77	39
43	Chamkar Leu	12.80	105.20	116	30	
44	Chamkar Andong	12.20	105.11	86	31	
45	Steng Trang	12.15	105.31	22	31	
46	Prek Kak	12.15	105.38	22	34	
47	Peam Chikong	11.52	105.32	n/a	4	
48	**Chalang**	11.52	106.15	210	29	
49	Memot	11.56	105.35	21	31	
50	Chup	11.49	106.16	212	33	
51	Suong	11.54	105.38	19	28	
52	Kantroy	11.49	106.18	210	29	
53	Krek	11.46	105.56	22	17	
54	**Kampong Tralach**	11.55	104.45	10	39	
55	Kampong Chnang	12.15	104.39	6	32	
56	Sdoch Ach Romeas	12.04	104.32	10	11	
57	**Kasmoul, Koh Kong**	11.26	103.01	1	21	
58	Sreambel	10.42	103.43	7	16	
59	**Siempang, Rat-kiri**	14.00	106.20	220	13	
60	VoeunSai	14.00	106.45	220	28	
61	**Chomksan, Phreah Vihear**	14.14	104.55	100	24	

Note: The Bold stations are still in operation until now, while the rests do not operate anymore.

Appendix 2.7.2: Rainfall Anomaly for Wet Season and Dry Season by Rainfall Region in the Period between 1980-2000


Anomaly May-Oct ,Re.II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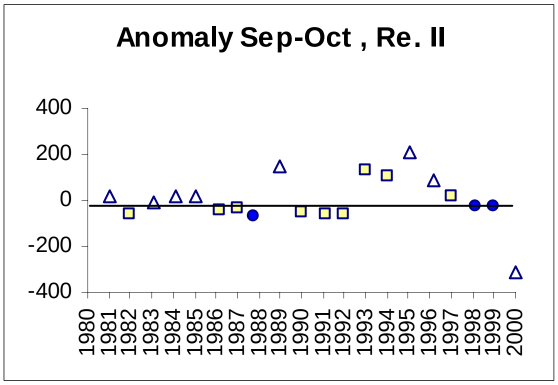
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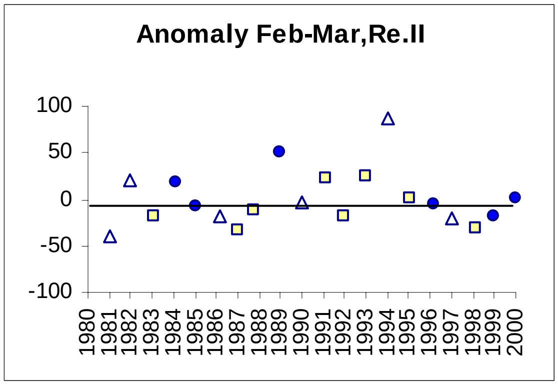
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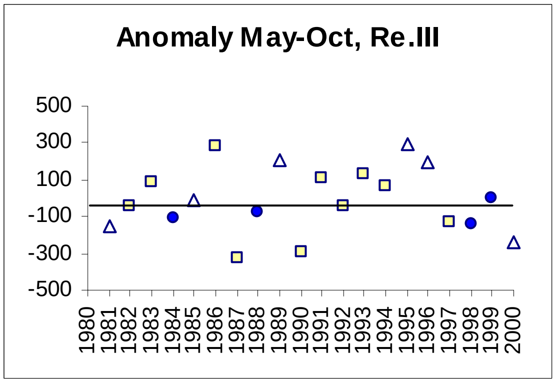
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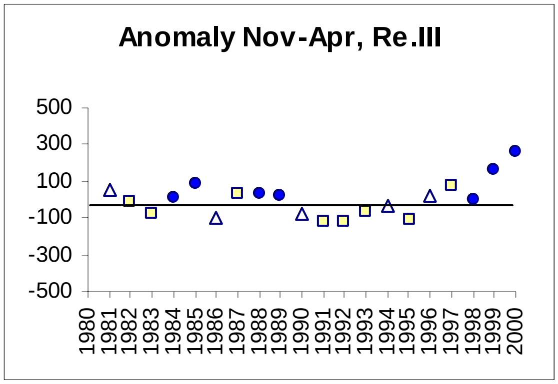
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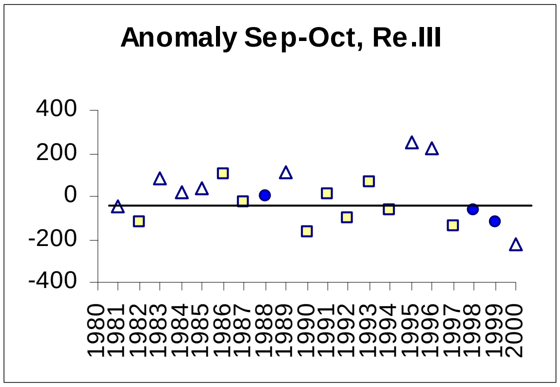
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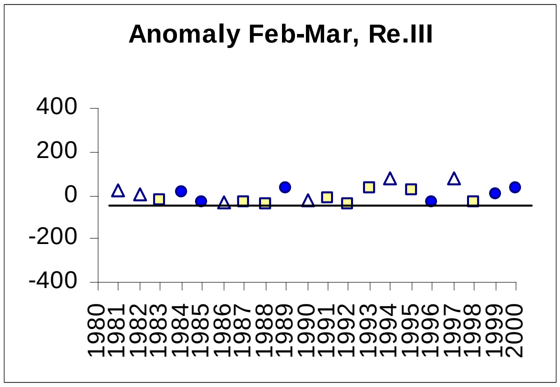
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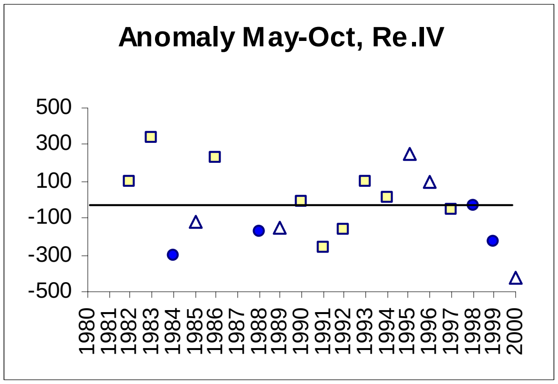
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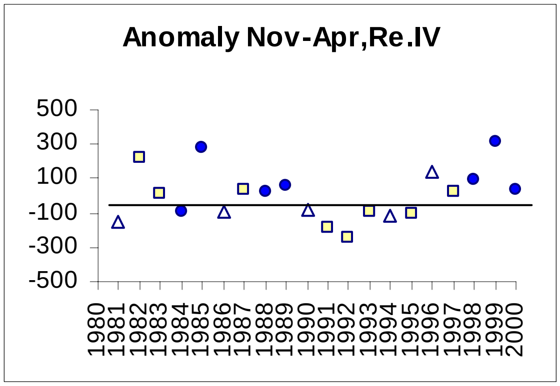
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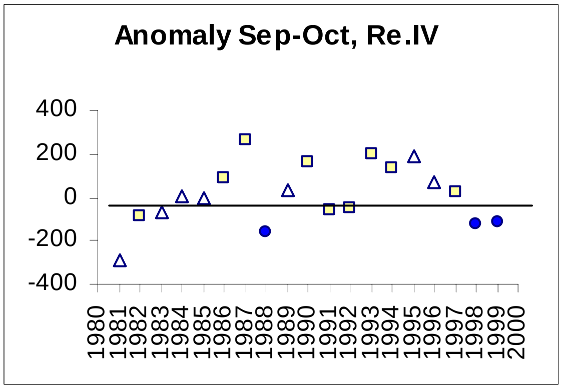
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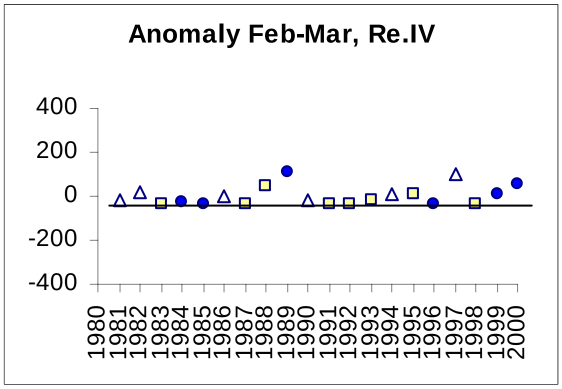
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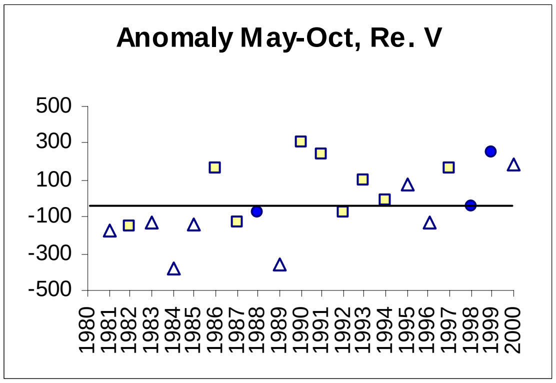
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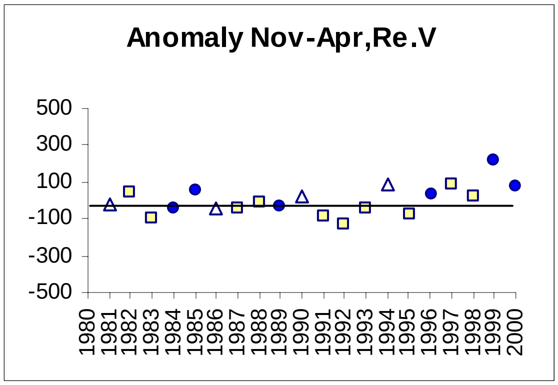
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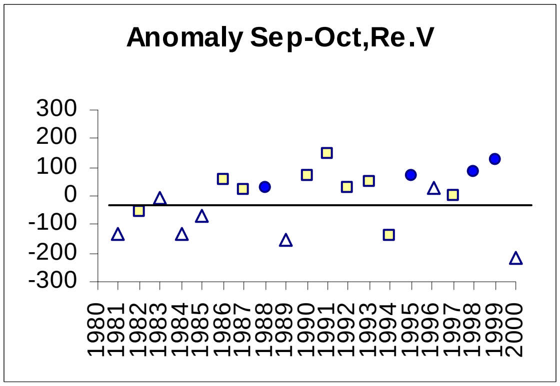
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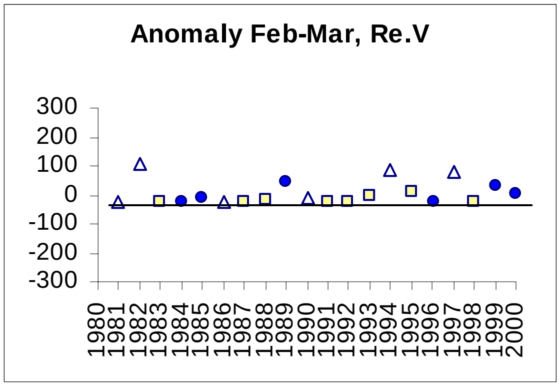
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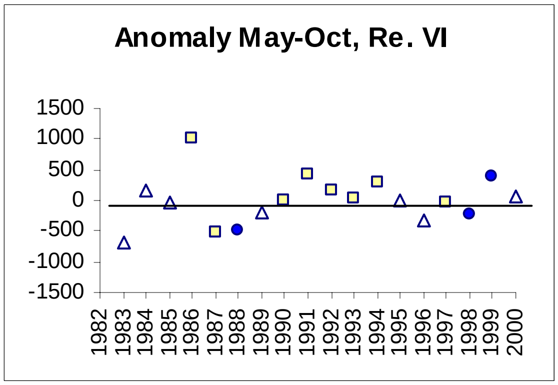
Anomaly May-Oct, Re. VI
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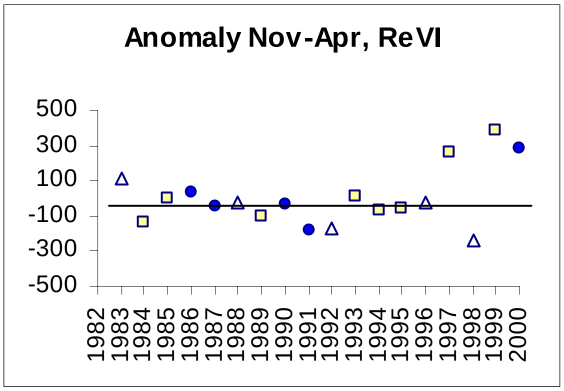
1000
500
0
-500
-1000
-1500
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000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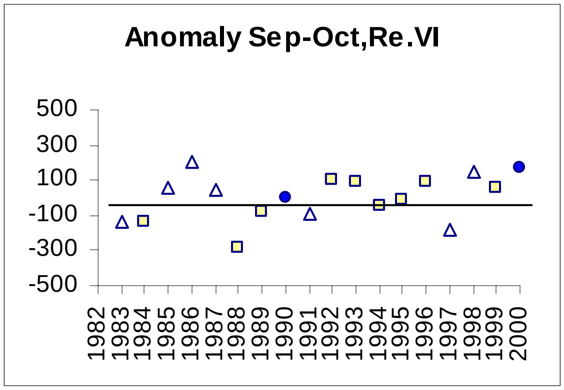
300
100
-100
-300
-500
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000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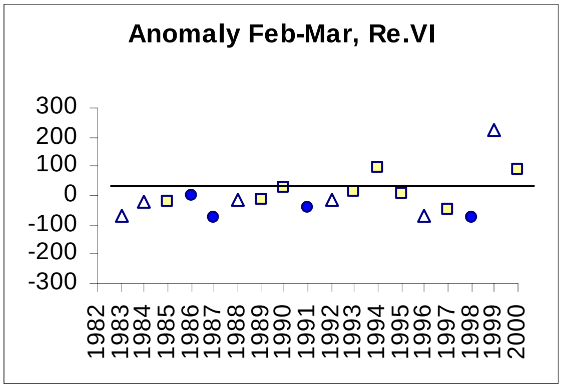
300
100
-100
-300
-500
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000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100
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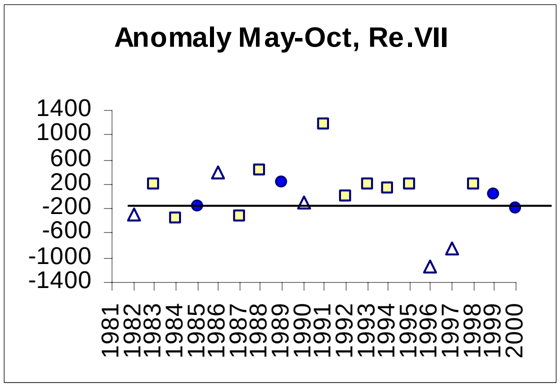
-100
-200
-300
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000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1000
600
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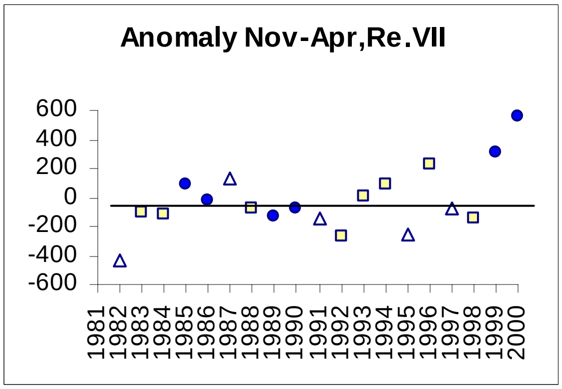
-200
-600
-1000
-1400
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000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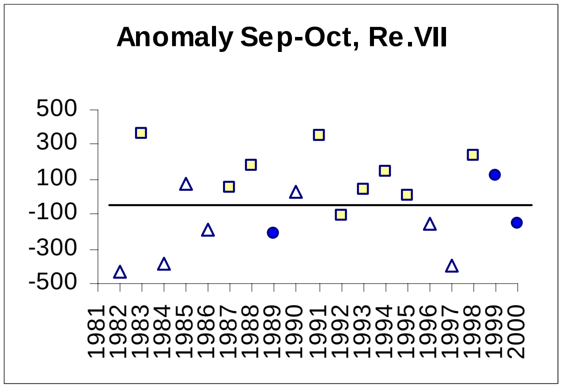
-600
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000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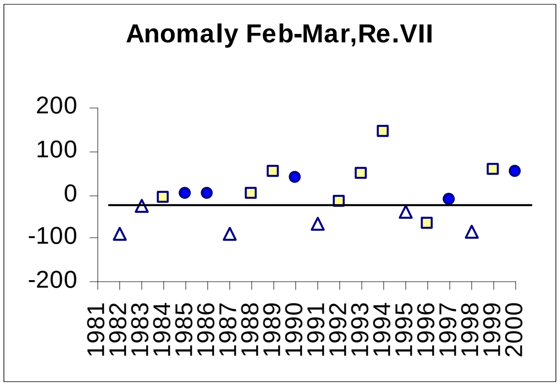
-100
-300
-500
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

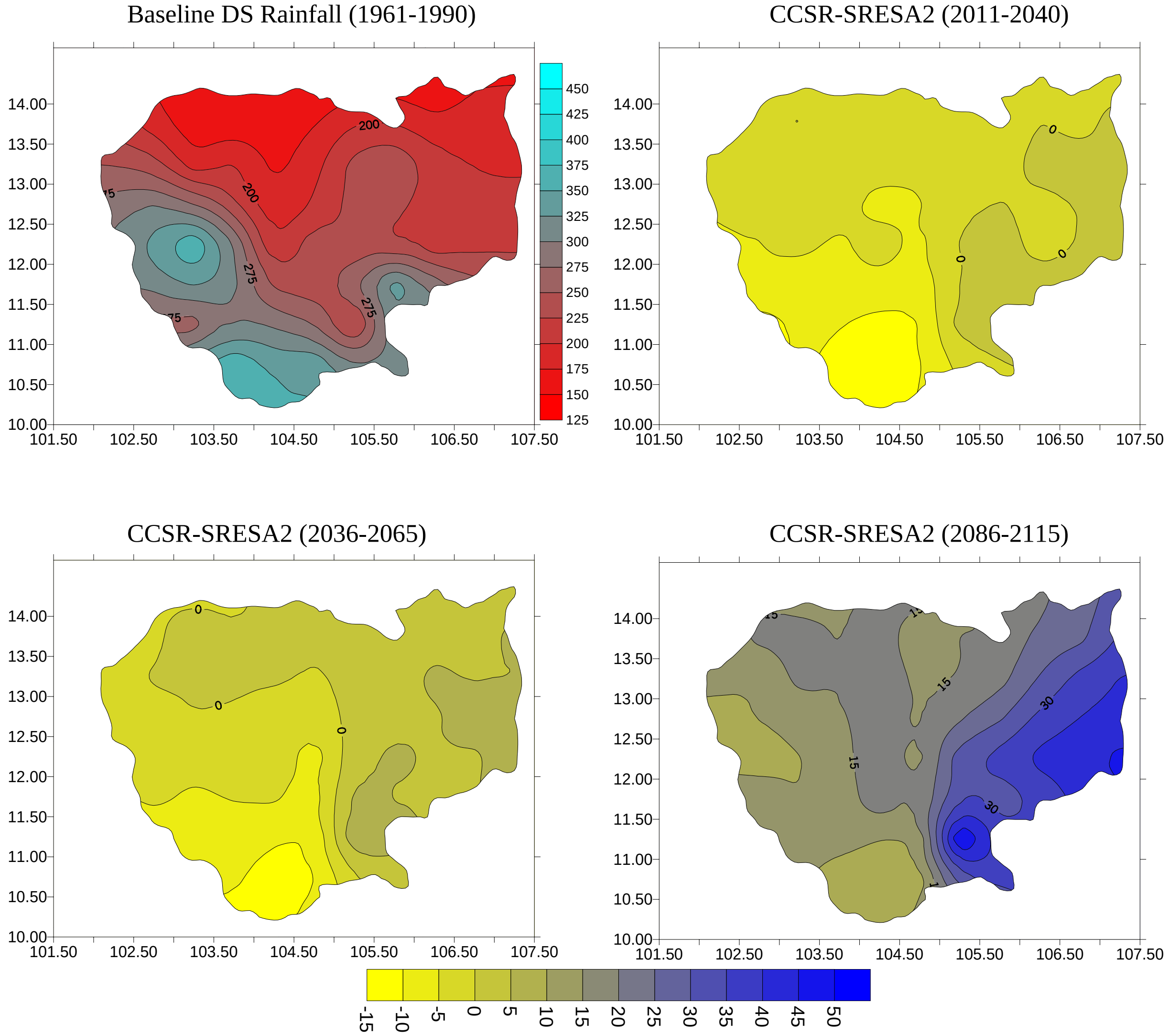

Anomaly Feb-Mar,Re.VII
200
100
0
-100
-200
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

Appendix 2.7.3: Mean of Deviation between Observed Rainfall and GCM Outputs in the Eight Rainfall Regions under Current Condition (1961-1990)

Region		N. Grid	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
I	Observation	6	2.17	9.33	24.8	62.6	144	154	161	159	210	165	62.4	11.9	**1166**
I	GCM	9	26.2	36.7	62.7	113	280	518	495	631	473	244	96.7	49.6	**3026**
I	**Difference**		**-24**	**-27.4**	**-37.9**	**-50.7**	**-136**	**-364**	**-334**	**-472**	**-263**	**-78.9**	**-34.3**	**-37.7**	
II	Observation	15	10.6	10.5	44.6	78.8	145	126	139	146	208	223	124	27.7	**1283**
II	GCM	8	42.2	49.7	78.3	120	348	721	629	823	574	302	143	77.9	**3908**
II	**Difference**		**-31.7**	**-39.2**	**-33.7**	**-41.2**	**-203**	**-595**	**-490**	**-677**	**-366**	**-79.5**	**-18.7**	**-50.2**	
III	Observation	13	14.7	14.6	28.8	73.3	179	209	215	214	262	202	78.5	20.9	**1513**
III	GCM	15	30.4	39.8	67.4	119	313	621	577	747	535	260	110	61.2	**3480**
III	**Difference**		**-15.7**	**-25.2**	**-38.6**	**-45.9**	**-134**	**-412**	**-361**	**-532**	**-273**	**-57.6**	**-31.5**	**-40.3**	
IV	Observation	4	28.1	14	31.7	109	194	175	177	201	267	304	177	61	**1738**
IV	GCM	5	48.4	53.8	86.2	130	377	858	747	995	656	329	155	86.8	**4522**
IV	**Difference**		**-20.2**	**-39.8**	**-54.5**	**-20.5**	**-183**	**-683**	**-570**	**-794**	**-389**	**-25.1**	**21.9**	**-25.8**	
V	Observation	11	7.55	15.3	44	91	214	256	300	300	319	223	86.9	23.9	**1879**
V	GCM	12	38.2	40.1	68.2	117	311	652	595	784	547	262	147	88.1	**3650**
V	**Difference**		**-30.7**	**-24.8**	**-24.2**	**-26**	**-97.1**	**-396**	**-295**	**-484**	**-229**	**-39.8**	**-60.1**	**-64.2**	
VI	Observation	7	9.54	15.7	46.2	132	299	317	359	330	407	308	124	31.5	**2380**
VI	GCM	4	69.8	59.5	91.5	125	375	915	789	1063	667	353	233	145	**4886**
VI	**Difference**		**-60.2**	**-43.8**	**-45.3**	**6.92**	**-76.4**	**-598**	**-430**	**-732**	**-260**	**-45.2**	**-109**	**-113**	
VII	Observation	3	13.9	19	70.4	121	279	451	585	582	497	273	87.2	23.6	**3002**
VII	GCM	9	45.1	38.3	67.5	118	279	629	568	772	555	268	196	138	**3674**
VII	**Difference**		**-31.2**	**-19.3**	**2.91**	**2.94**	**0.26**	**-178**	**16.5**	**-190**	**-58.7**	**5.54**	**-109**	**-115**	
VIII	Observation	2	11.3	35.8	92.8	124	418	685	885	809	642	319	121	42.8	**4185**
VIII	GCM	5	81.8	61.6	90.5	113	353	830	709	952	589	350	284	164	**4577**
VIII	**Difference**		**-70.6**	**-25.9**	**2.23**	**11.6**	**64.7**	**-145**	**176**	**-143**	**53.5**	**-31**	**-164**	**-121**	

Appendix 2.7.4: Maps Showing Isohyets of Dry Season and Wet Season Rainfall under SRESA2 and SRESB1 for the two GCM Models under Current and Future Climate

(a) Dry season rainfall at current conditions (mean of 1961-1990), and percent change of dry season rainfall for 2025 (mean of 2011-2040), 2050 (mean of 2036-2065) and 2100 (mean of 2086-2115) using CCSR GCM Model and Emission Scenario of SRESA2



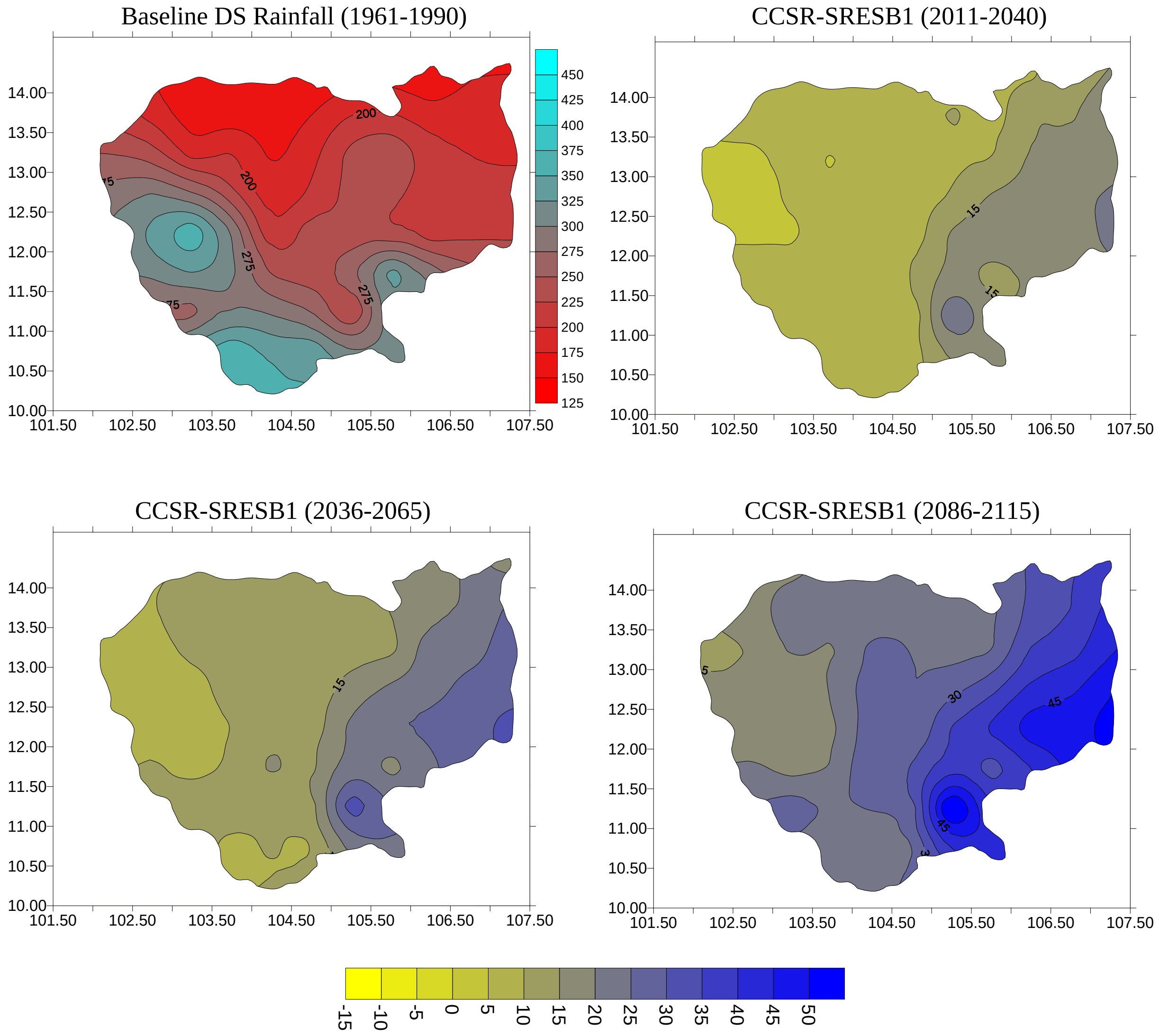
Baseline DS Rainfall (1961-1990)

CCSR-SRESA2 (2011-2040)

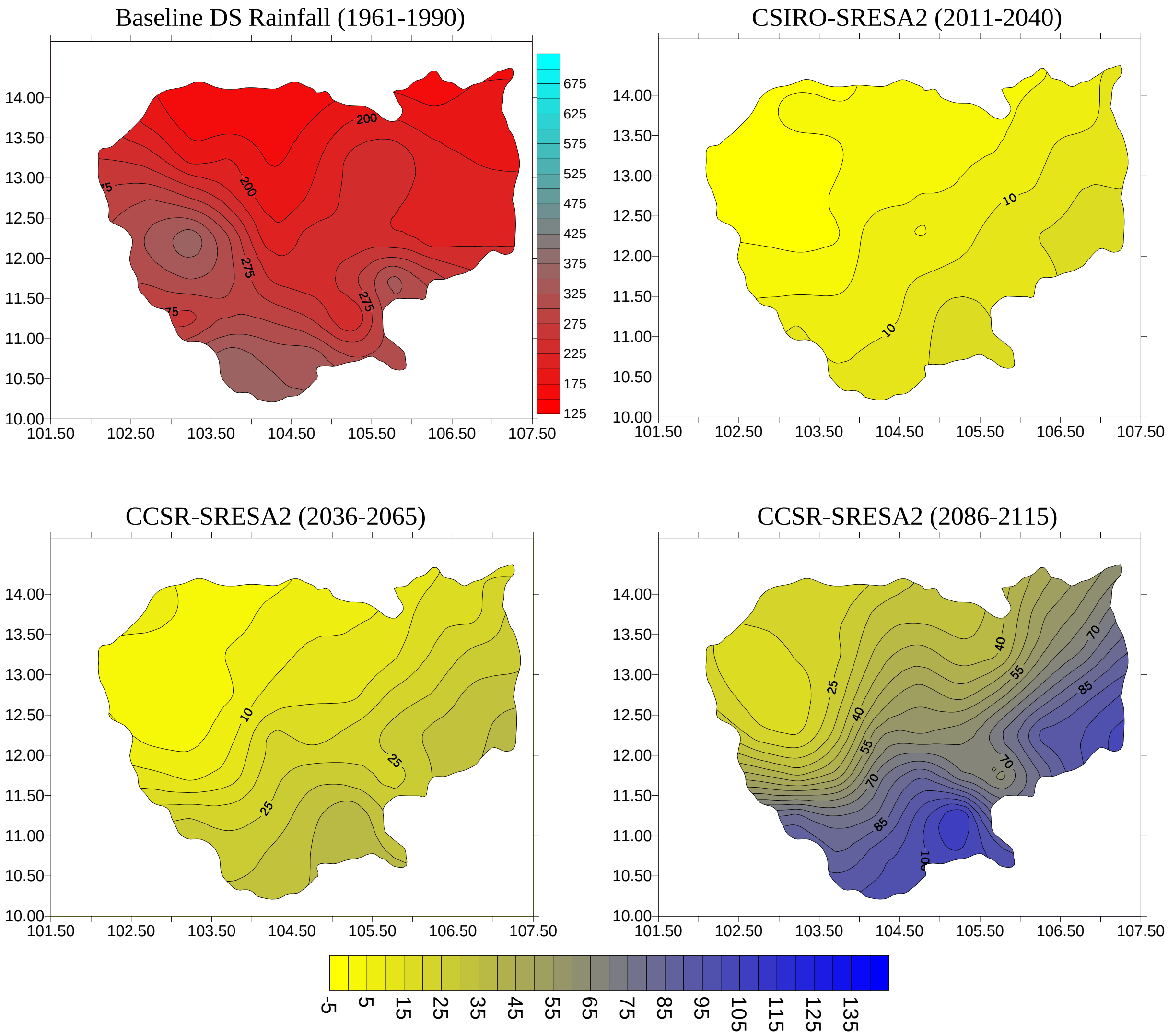
CCSR-SRESA2 (2036-2065)

CCSR-SRESA2 (2086-2115)

(b) Dry season rainfall at current conditions (mean of 1961-1990), and percent change of dry season rainfall for 2025 (mean of 2011-2040), 2050 (mean of 2036-2065) and 2100 (mean of 2086-2115) using CCSR GCM Model and Emission Scenario of SRESB1



(c) Dry season rainfall at current conditions (mean of 1961-1990), and percent change of dry season rainfall for 2025 (mean of 2011-2040), 2050 (mean of 2036-2065) and 2100 (mean of 2086-2115) using CSIRO GCM Model and Emission Scenario of SRESA2



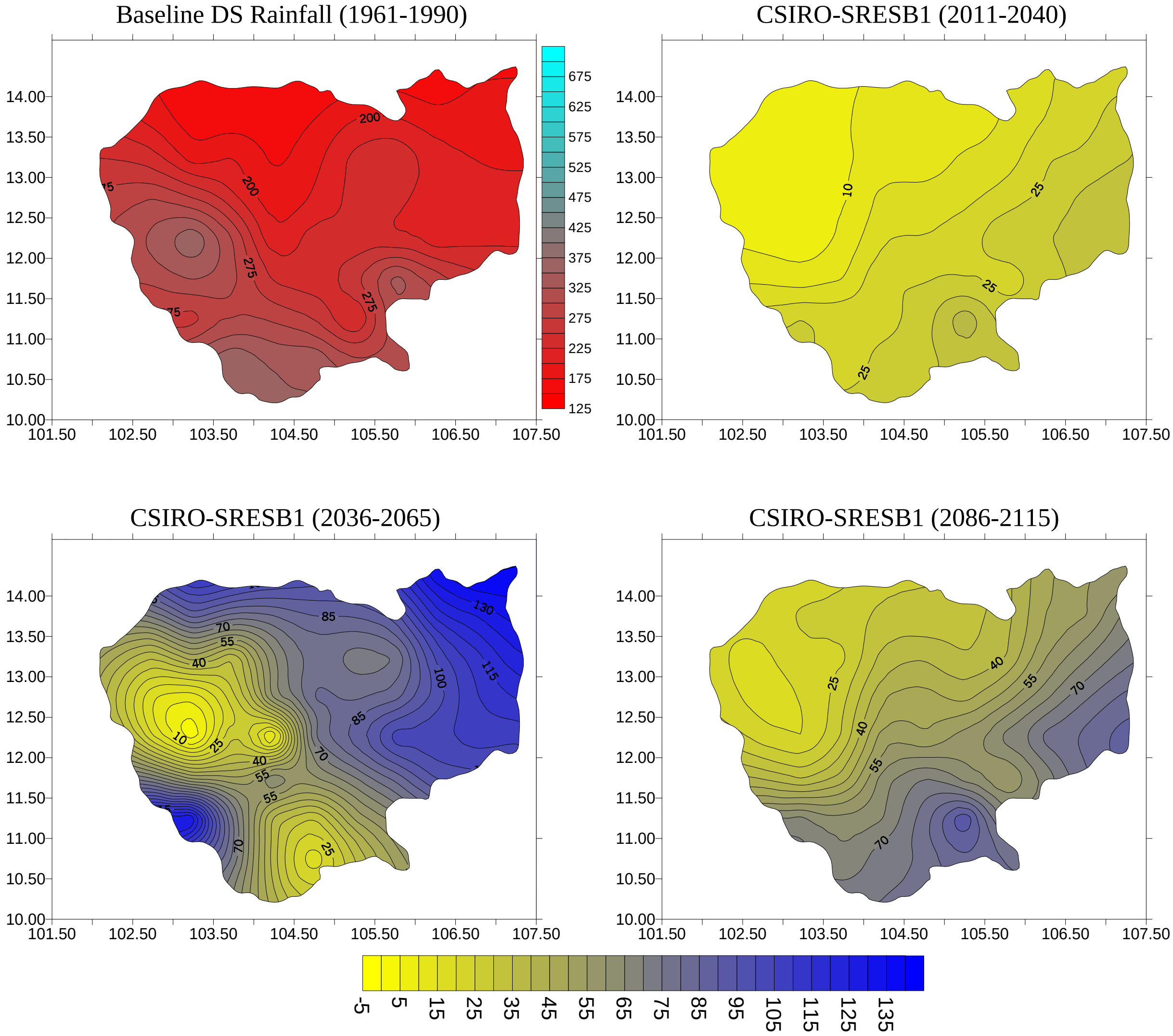
Baseline DS Rainfall (1961-1990)

CSIRO-SRESA2 (2011-2040)

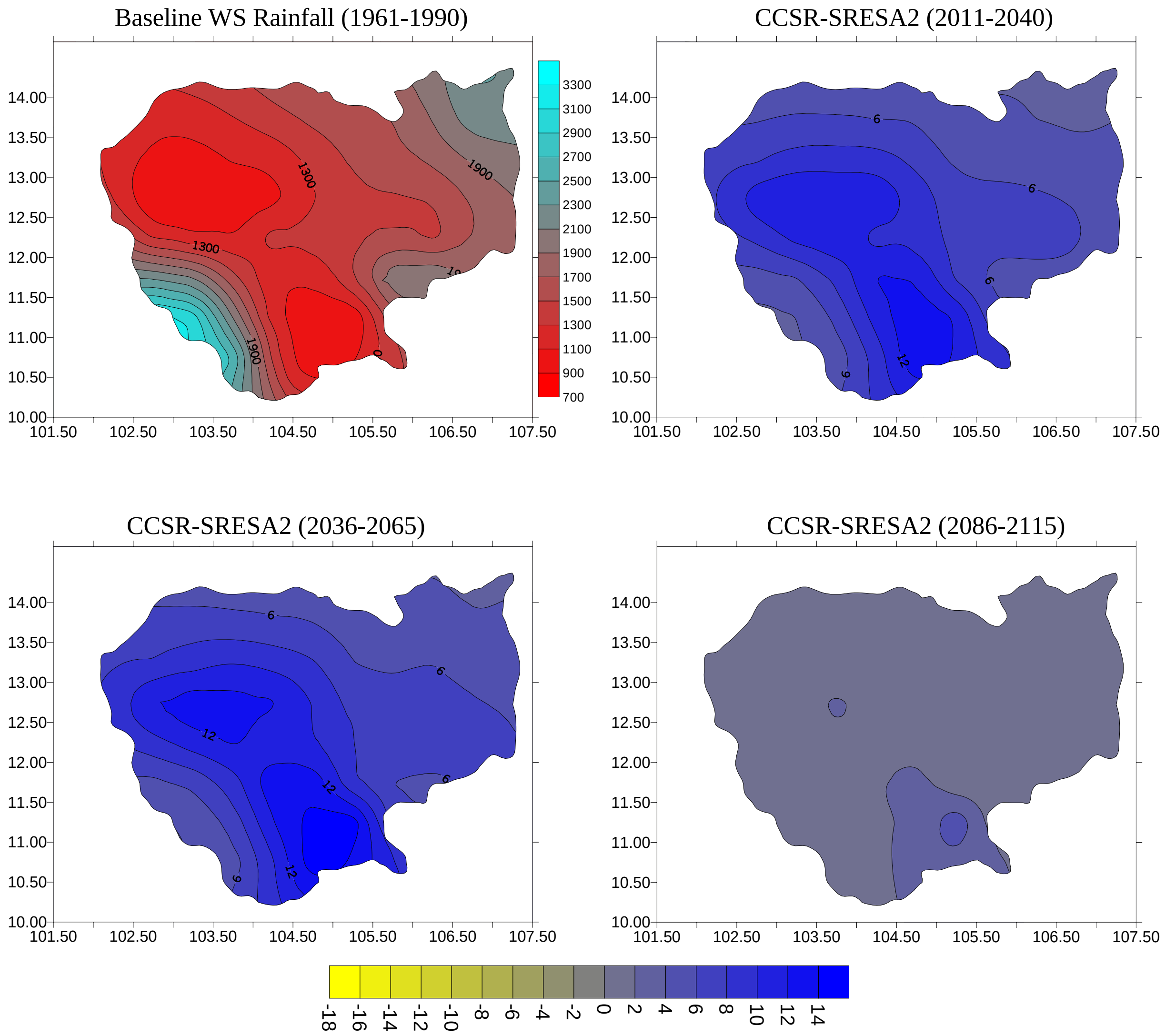
CCSR-SRESA2 (2036-2065)

CCSR-SRESA2 (2086-2115)

(d) Dry season rainfall at current conditions (mean of 1961-1990), and percent change of dry season rainfall 2025 (mean of 2011-2040), 2050 (mean of 2036-2065) and 2100 (mean of 2086-2115) using CSIRO GCM Model and Emission Scenario of SRESB1



(e) Wet season rainfall at current conditions (mean of 1961-1990), and percent change of wet season rainfall for 2025 (mean of 2011-2040), 2050 (mean of 2036-2065) and 2100 (mean of 2086-2115) using CCSR GCM Model and Emission Scenario of SRESA2



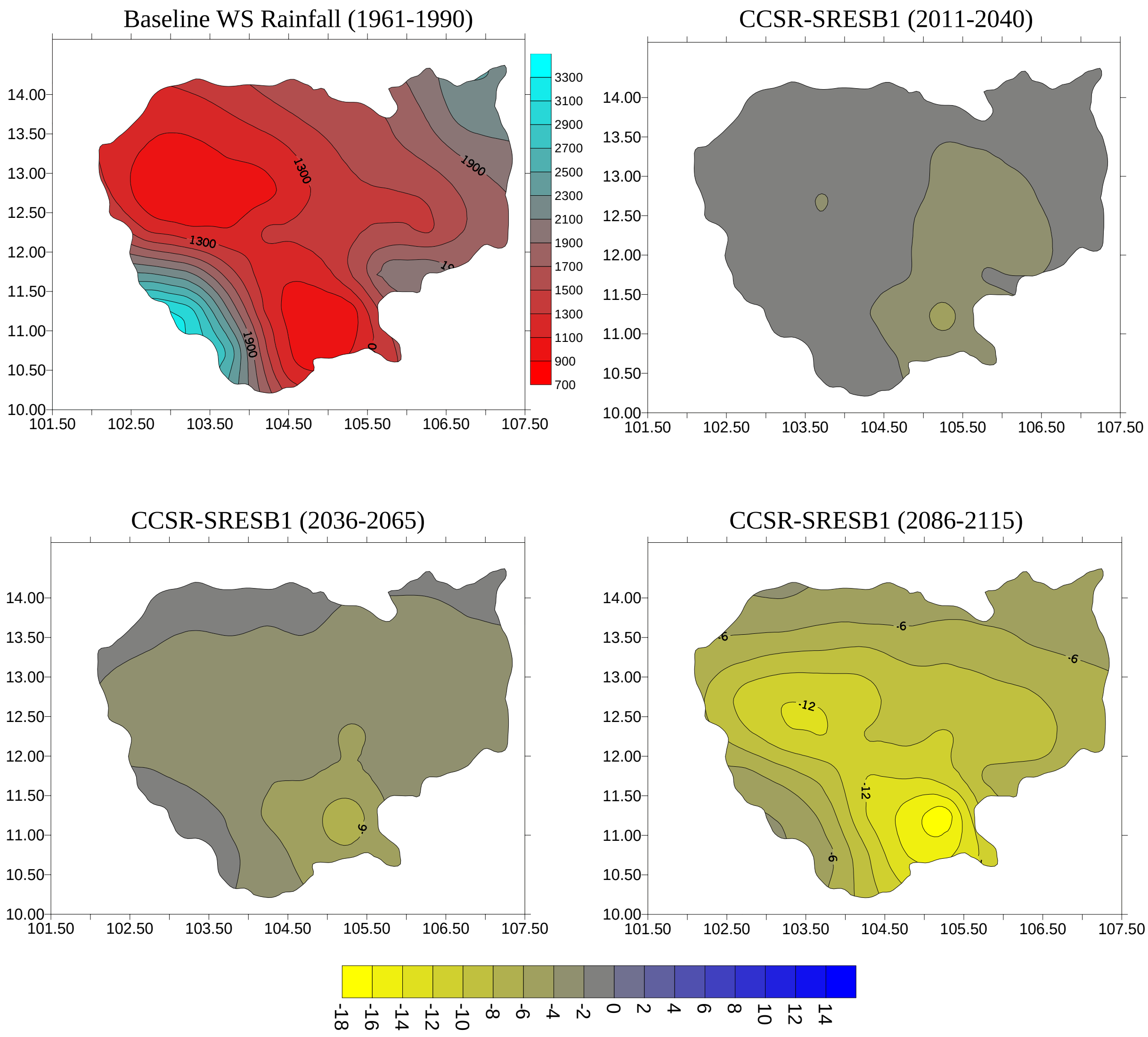
Baseline WS Rainfall (1961-1990)

CCSR-SRESA2 (2011-2040)

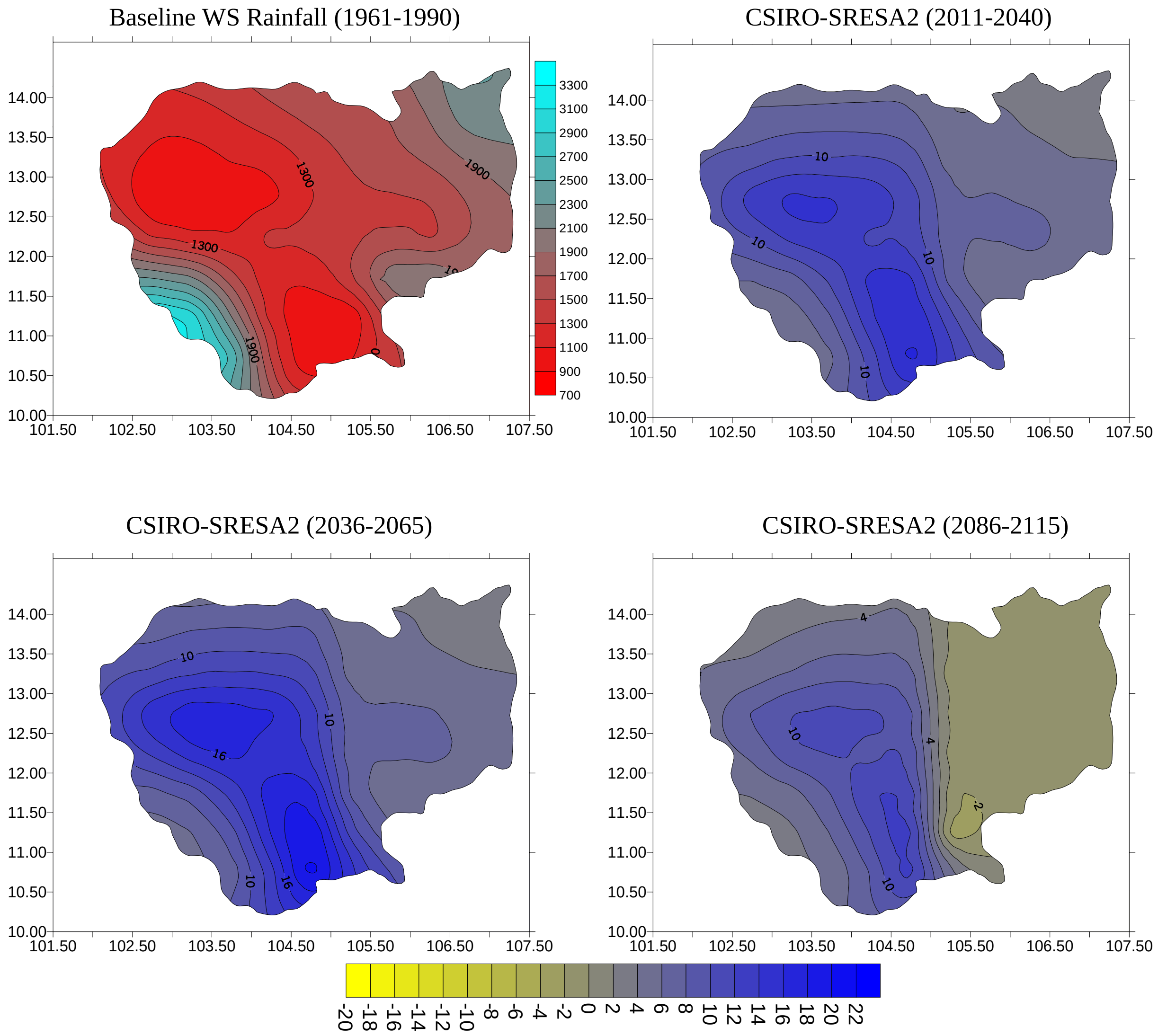
CCSR-SRESA2 (2036-2065)

CCSR-SRESA2 (2086-2115)

(f) Wet season rainfall at current conditions (mean of 1961-1990), and percent change of wet season rainfall for 2025 (mean of 2011-2040), 2050 (mean of 2036-2065) and 2100 (mean of 2086-2115) using CCSR GCM Model and Emission Scenario of SRESB1



(g) Wet season rainfall at current conditions (mean of 1961-1990), and percent change of wet season rainfall for 2025 (mean of 2011-2040), 2050 (mean of 2036-2065) and 2100 (mean of 2086-2115) using CSIRO GCM Model and Emission Scenario of SRESA2

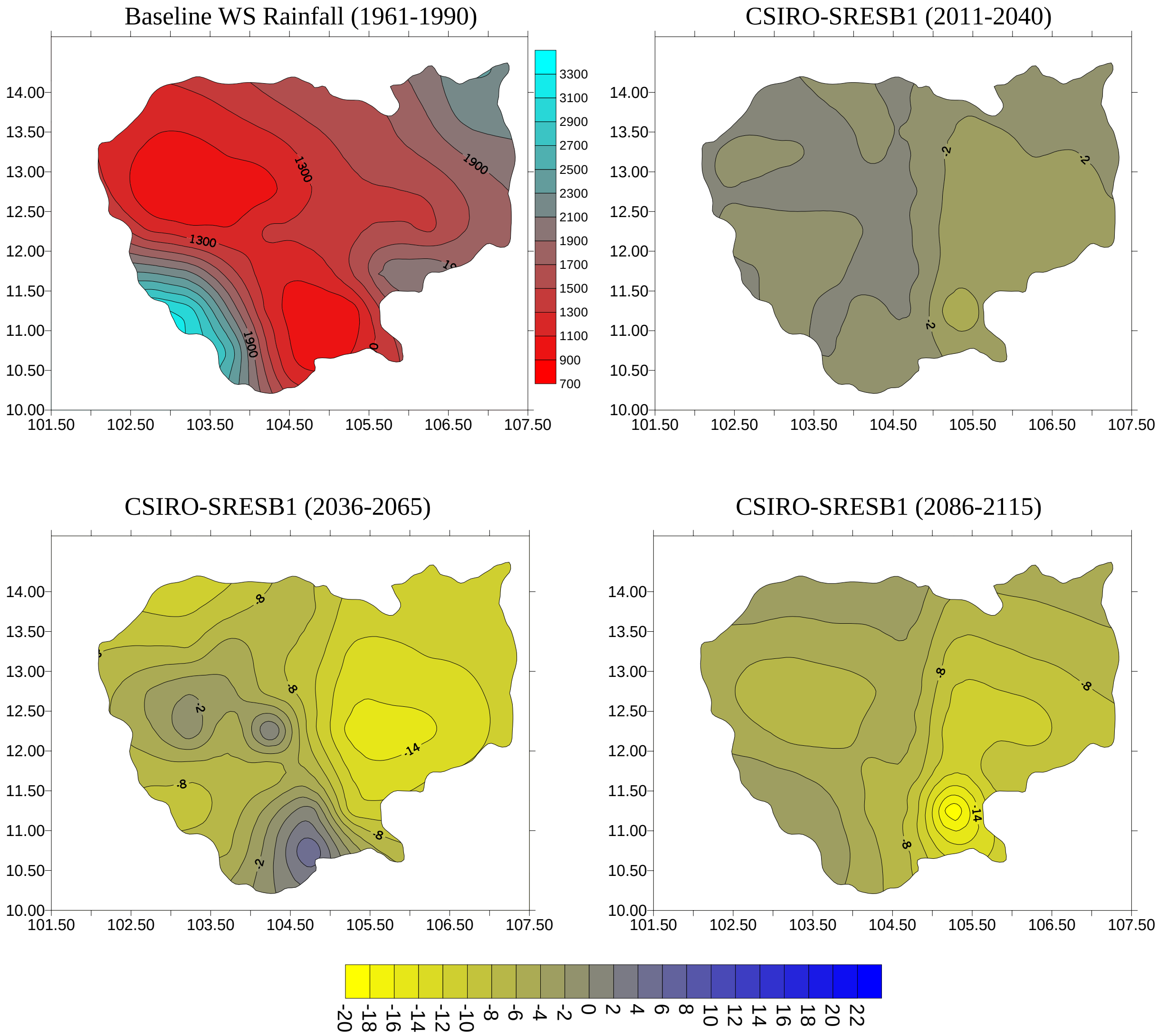

Baseline WS Rainfall (1961-1990)

CSIRO-SRESA2 (2011-2040)

CSIRO-SRESA2 (2036-2065)

CSIRO-SRESA2 (2086-2115)

(h) Wet season rainfall at current conditions (mean of 1961-1990), and percent change of wet season rainfall for 2025 (mean of 2011-2040), 2050 (mean of 2036-2065) and 2100 (mean of 2086-2115) using CSIRO GCM Model and Emission Scenario of SRESB1



III. VULNERABILITY AND ADAPTATION FOR AGRICULTURE

III.1. Introduction

The agriculture sector contributes to about half of Cambodia's GDP. Approximately 80-85% of the population is engaged in agriculture related-activities. Agriculture crops contribute 63%, while livestock, fisheries and forestry contribute 24%, 10% and 3% respectively to GDP. Among agricultural crops, rice is the primary crop covering about 90% of the current cropped area (± 2.5 million ha) (Cambodia: First State of the Environment Report, 1994). Seasonal variations in the rice production are also dramatic, with more than 90% of rice cultivation occurring in the wet season and less than 10% in the dry season (Nesbitt, 1996).

The national rice productivity in Cambodia in 1995 is one of the lowest in Asia, at 1.5 t/ha. This low yield is due to poor water management, low technology inputs and poor seed quality. However, in the last 10 years, rice production has increased significantly as a result of increasing cultivated area and productivity. The area of wet season rice increased from 1.7 million ha in 1993 to 1.9 million ha in 1998, while that of dry season rice increased from 155,000 ha in 1993 to 231,000 ha in 1998. Rice yields also increased from 1.3 to 1.6 t/ha for wet season rice and from 2.8 to 3.0 t/ha for dry season rice. This increase is due to increases in fertilizer use and the use of better technology to protect the crop from pests and diseases. This increase has changed Cambodia from a rice importing-country in 1993 to a rice-exporting country in 1996. Since 1996, the volume of export has been in excess of 100,000 tonnes per year (Agriculture Development Plan, 1999). This trend seems likely to continue through research activities such as development of high yielding varieties (HYV) and improvement of crop management.

Variability of rice production in Cambodia is significantly correlated with climate variability particularly due to the occurrence of floods and droughts. The major rice growing areas of the Mekong-Tonle Sap basin flood every year but, in some years, extreme flooding causes problems. Extended periods of flooding in the Mekong river and Tonle Sap have ruined many deepwater rice crops. In recent El-Nino and La-Nina years (1997-1998), Cambodia experienced a prolonged dry season, followed by a month of heavy rains resulting in flash floods that destroyed crops. In 1996, a La-Nina year, 457,500 ha of 1.9 million ha wet season rice suffered from flooding. In a normal year, the area experiencing floods is approximately 10,000 ha (Agricultural Statistics 1993, 1996). In agriculture areas where temporary flooding occurs, floods cause serious germination problems for some direct-seeded rice and most upland crops including legumes.

In addition to drought, pests and diseases are also limiting factors for food crop production in Cambodia. The major pests of rice are gall midge, stem borer, brown plant hopper, green leafhopper, grasshopper, leaf folder, rice bug, case worm, army worm and rats. Indications are that populations of some of these pests increase significantly under extreme climate conditions. Since climate variability is a significant factor in agricultural production in Cambodia, with extreme climatic events such as floods and droughts already causing a great deal of destruction, efforts to adapt to these events could help to reduce damage in the short term, regardless of any longer-term changes in climate.

The objectives of this study are:

- To evaluate the impact of climate extremes on crop production in Cambodia in more detail;
- To study the vulnerability of agricultural sector to climate change; and
- To develop possible adaptation options for agricultural sector, in particular rice crops, to climate change.

III.2. Climate Variability and Rice Production

III.2.1. Agriculture Production in Cambodia

The contribution of the agriculture sector in Cambodia to the National GDP is significant, i.e. 45.2%. The Government of Cambodia plans to maintain this and therefore efforts are being made to increase the income from the agriculture sector through the improvement of quality and quantity of products. Based on historical data from 1980 to 1999, agriculture production has increased between 1.4 and 7.8% per annum, except for corn, sweet potato and jute (Table 3.1). Rapid growth rates (more than 5% per annum) have been observed for soybean, pig, poultry, fish, cattle, peanut and sesame. By comparing the growth rates of Table 3.1 and 3.2, the increase in crop production for some commodities can be attributed to the increase in harvested area as opposed to increases in productivity. Sweet potato, mungbean and soybean are notable examples where the growth rate of crop production was equal to or lower than that of harvested area.

Table 3.1: Growth of Agriculture Production by Commodity (1980-1999)

Agriculture Product	1980	1985	1990	1995	1999	Annual Growth Rate (%)
Paddy Rice ('000 tonne)	1717.0	1812.0	2500.0	3452.0	4040.9	4.8
Corn ('000 tonne)	101.0	42.0	88.0	54.9	95.3	-0.1
Cassava ('000 tonne)	152.0	17.0	60.0	81.0	228.5	3.9
Sweet potato (tonne)	45.0	15.0	31.0	39.1	32.5	-0.1
Mung bean (tonne)	10.0	21.0	12.0	19.6	15.9	1.4
Peanut (tonne)	3.0	5.0	4.0	6.8	9.2	5.2
Soybean (tonne)	3.0	13.0	22.0	17.2	35.1	7.8
Sesame (tonne)	1.0	6.0	5.0	3.8	8.4	5.3
Sugarcane (tonne)	40.0	169.0	258.0	202.5	159.9	3.6
Tobacco (tonne)	-	5.6	7.8	11.1	6.4	1.8
Jute (tonne)	0.2	3.4	1.6	1.0	0.3	-3.6
Poultry ('000 heads)	2442.0	6398.0	8163.0	10066.7	13417.0	6.6
Water buffalo ('000 heads)	375.8	613.0	736.0	764.7	653.9	2.4
Pig ('000 heads)	132.1	1203.0	1515.0	2043.9	2189.4	7.3
Cattle ('000 heads)	772.0	1559.7	2181.0	2785.7	2826.4	5.5
Fish ('000 tonne)	19.6	70.6	111.4	112.5	124.1	6.0

Source: Ministry of Planning (2001).

Table 3.2: Growth of Harvested Area ('000 ha) by Commodity (1980-1999)

Commodity	1980	1985	1990	1995	1999	Annual Growth Rate (%)
Rice	1440.0	1450.0	1855.0	1924.0	2079.4	2.1
Corn	101.0	46.0	45.0	45.0	59.7	-3.0
Sweet Potato	9.0	5.0	8.0	9.4	9.3	1.3
Cassava	19.0	8.0	11.0	12.4	14.0	-1.0
Mungbean	16.0	39.0	25.0	25.2	26.8	0.6
Peanut	4.0	9.0	6.0	9.0	10.6	3.5
Soybean	5.0	10.0	15.0	16.2	35.0	8.3
Sesame	3.0	11.0	10.0	8.3	16.4	5.1
Sugarcane	2.0	8.0	6.0	7.4	8.4	4.0
Tobacco	0.0	11.3	15.6	13.4	8.3	4.2
Jute	0.3	2.1	1.6	0.9	0.3	-2.3
Cotton	0.2	0.8	0.9	0	0	-6.4
Black Pepper	0.0	0.1	0.3	0	0	1.8
Rubber	5.0	26.3	51.1	44.0	36.7	5.3

Source: Ministry of Planning (2001).

III.2.2. Rice Production and Climate Variability

Rice is the staple food for Cambodians and therefore it receives more attention in agricultural development and consequently the economy of the country. Rice production has steadily increased since 1980 at a rate of 4.5% per year (105,000 tonne per year) due to the increase in harvested areas and productivity (Figure 3.1). The rate of increase in harvested areas has been approximately 2.3% per year (382 thousand ha per year). Most rice growing areas are dominated by wet season rice (rainfed rice), while dry season rice (irrigated rice) accounts for 10% of the total productivity. It also appears that the rate of increase in rice productivity for wet season rice (1.9%) is lower than that of dry season rice (2.8%). After 1992, it was observed that the productivity of dry season rice increased quite significantly from about 2 to 3 t/ha and has remained relatively constant after 1994. In comparison with neighboring countries, rice productivity of Cambodia is low. Rice productivity of irrigated rice in Thailand, Indonesia and the Philippines commonly reaches 6-8 t/ha. Therefore, the opportunities for Cambodia to increase rice productivity are relatively high. Rice management technologies available in other neighboring countries can be easily adopted. Studies related to socio-economic condition of farmers and government policy on agriculture development need to be supported either through bilateral or multilateral funding mechanisms.

Figure 3.1 shows the fluctuation of rice production in Cambodia from 1980 to 2001. Based on the past five years data, production loss was mainly due to the occurrence of flooding (more than 70%) and followed by drought (about 20%) with insignificant production losses due to pests and diseases (Figure 3.2a). However, the occurrence of flood and drought have not always coincided with the occurrence of ENSO events (Figure 3.2b). Most floodings occur due to the increased water levels in the Mekong River and Tonle Sap Lake. These two water bodies link each other. The Mekong River starts from the Tibet plateau. The increase of water level in the Mekong River is therefore closely related with the rainfall occurrence throughout the basin. This might explain why the flood occurrence was not always related with Cambodian rainfall. There fore a study to investigate relationship between ENSO events and regional rainfall in Tibet and its impact on the Mekong River may be required.

Significant production losses in 2000 were due to the increased water level of the Mekong river during the period between early July and early October. This flood reportedly destroyed more than 401,379 ha of rice growing areas along the Mekong river and Mekong basin. Furthermore in mid October, this flood continued due to the occurrence of heavy rainfall in the west of the country. It is also worth adding that floods not only destroy rice crops but also infrastructure (irrigation facilities etc.). However, it should be noted that in some cases the crop may be flooded for a short period and then recovers to produce a good yield while in the statistics the result is a failed crop.

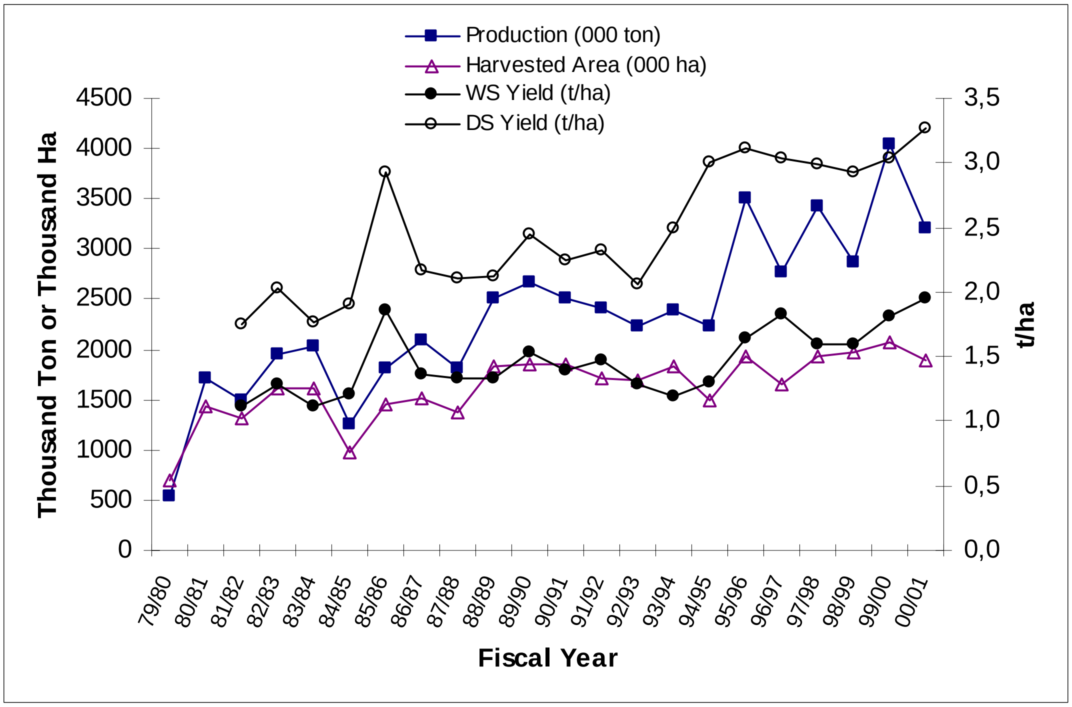


Figure 3.1: Trend of Rice Production, Productivity and Harvested Area

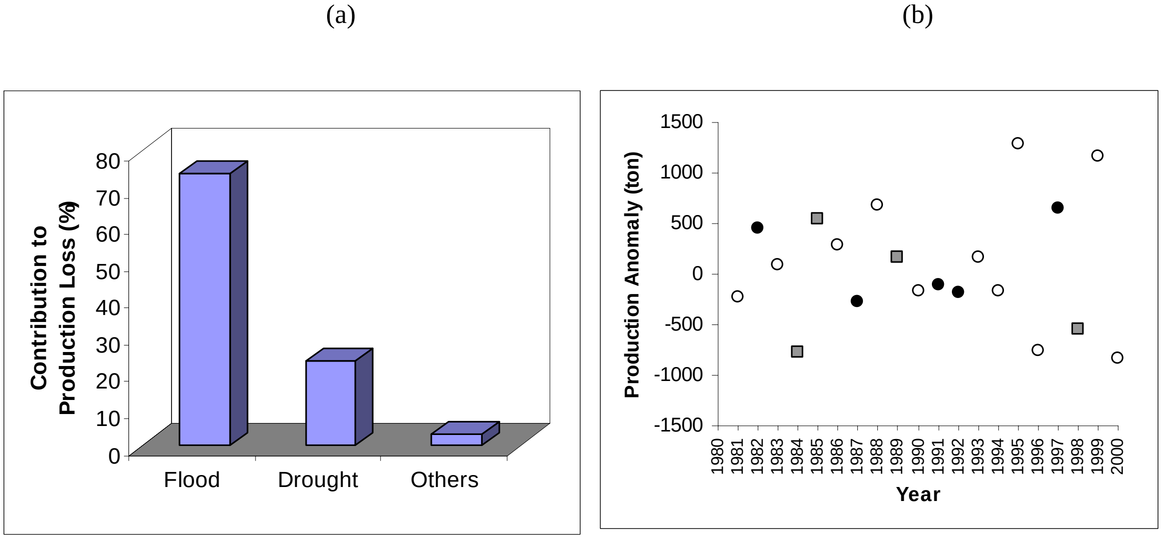


Figure 3.2: (a) Contribution of Natural Hazard to Rice Production Loss in Cambodia and (b) Production Anomaly (black circles represent El-Nino years, shaded squares represent La-Nina and white circles represent normal years)

III.2.3. Government Plan for Increasing Rice Production

The main purpose of agriculture, forestry and fisheries development in Cambodia is to ensure food security, to conserve national resources and to maintain the share of these sectors of national GDP at 45-50%. This means that the growth of this sector needs to be maintained at a rate of about 5% per annum (Agricultural Development Plan, 1999-2010). The Government has set up a development plan for these sectors up to year 2010. The policies and programs are as follows:

1. ***Agricultural Crops***. Increasing crop production in particular rice through extensification program (expanded cultivated area to 2.5 million ha). Intensification program would not be the main focus for rice as the expected increase in rice productivity in the next 10 years was only 0.1 t/ha. Efforts to increase yields and quality of agriculture products would be done through the creation of research and extension activities and the use of more advanced technology. However, it should be noted that several intensification projects are underway with support from bilateral and multilateral donors. The cultivated area of crops other than rice would be created in the form of family and private investment with diversification of rural economy activities would be also promoted. The agriculture sector development would therefore be an integration of diversification, extensification and intensification programs aimed at ensuring a continuous supply of products to local markets, to reduce import and to increase export.

2. ***Livestock***. Increasing quantity of meat supply for domestic consumption and export.

3. ***Forestry and Fisheries***. Maintaining sustainability of natural resources and developing aquaculture, inland and marine fishery research. Reforestation and restoration of natural inundated forest and aquaculture would receive serious attention.

In term of increasing rice production, the Royal Government of Cambodia has launched programs and policies as follows:

- Continuing the implementation of irrigated-water policies;
- Expanding irrigated areas from 16-20% of the total cultivated area;
- Expanding the rice cultivated area up to 2,500,000 ha in year 2010;
- Increasing yield and production of rice at a rate of 2.7% per annum and improving the quality of agricultural products;
- Improving technology application and other infrastructures for reducing dependency on the nature;
- Promoting agricultural diversification; and
- Increasing planting index through crop rotation or inter cropping.

Based on the above programs, a projection of rice growing areas, yield, demand and supply has been developed. It is expected that by 2020 Cambodia might be in a position to export as much as 2 million tonnes of rice per year if all programs are successfully implemented (Table 3.3).

Table 3.3: Projection of Rice Cultivated Area, Supply and Demand

Description		2000	2010	2020
Cultivated area (ha)	Wet season (rainfed)	1,987,566	2,051,887	2,540,000
	Dry season (irrigated)	253,000	448,113	510,000
	Total area	2,240,566	25,000,00[1]	3,050,000
Yield (t/ha)	Wet season (rainfed)	1.95	2.02	2.34
	Dry season (irrigated)	3.27	3.39	3.94
	National average	2.12	2.2[1]	2.61
Production (tonne)	National	4,026,092	5,663,915	7,953,000
Rice Demand (tonne)	National	3,196,400	3,618,800	3,999,100
Population (million)[2]	National	13.1	16.6	20.3
Rice Consumption (kg/cap)	National	244[3]	218	197
Surplus (tonne)	National	829,692	2,045,115	3,953,900

Source: [1] MAFF (1999); [2] National Institute of Statistics (2000); [3]MAFF (2001). Projection to 2020 was developed considering GDP growth.

III.3. Vulnerability and Adaptation of Cambodia's Agriculture to Climate Change

Assessment of the impact of climate change on agriculture was only carried out for rice. This is because the rice commodity is the main staple food in Cambodia and also a major contributor to the country's income. The assessment was done using a stochastic approach rather than a deterministic approach since the later approach requires more data inputs.

III.3.1. Methodology

The impact of changing climate on rice production in Cambodia was evaluated using several steps of analysis. The first step was to analyze the trend of rice production in selected provinces (four main rice growing areas, i.e. Prey Veng, Takeo, Kampong Cham and Battambang). This analysis was performed using regression techniques with the year as the independent variable, and wet season and dry season rice productivity as the dependent variable. The second step was a calculation of the anomaly of rice productivity (the difference between observation and estimated data derived from equation developed in step 1). The third step was to develop a model for estimating anomalies of rice productivity from monthly rainfall in each province. Rainfall data from the two GCMs (see Chapter 2) run under two emission scenarios was then used as inputs for the model developed in step three. This choice of analysis was motivated by the necessity to remove the impact of technology changes on rice productivity.

Change in crop productivity under changing climate is not only due to changes in rainfall since the changing climate would occur under increasing global temperature resulting from increasing CO_2 concentration in the atmosphere. Under elevated CO_2, crop productivity would increase, while under increasing temperature crop productivity will decrease due to shortening of growing season for non-photoperiod sensitive crops. A study[1] conducted by Squire and Unsworth (1988) showed that when daily temperature were increased by 3^oC and CO_2 was doubled, more rapid development of crops shortened the growing season, and the potential grain yield was only 15% larger than in the control, but maturity occurred 30 days earlier. A combination of $+4.5^oC$ and doubled CO_2 resulted in the temperature and CO_2 factors almost canceling out, so that the potential grain yield was only 8% larger than the control.

Considering the above facts, estimated rice productivity resulting from equation developed in step three above was then adjusted by multiplying the estimated value with correction factors, a function of CO_2 concentration and temperature. The first correction factor accommodates the impact of increasing CO_2 and the second factor accommodates the impact of increasing temperature. Goudriaan & Unsworth (1990) proposed the following equation to estimate correction factor for CO_2:

$$CF_{[CO2]} = [1+b\mathrm{Ln}(C/C_0)]\ P_0$$

where 0 stands for baseline situation (current condition), P - crop productivity, and C - ambient CO_2 concentration. Estimated value for b is 0.7. This equation, however, is only indicative and has no physiological meaning. However it serves well to summarize many observations and simulation results (Goudriaan & Unsworth, 1990). Based on the above fact that 4.5^oC increase in temperature canceled out the impact of doubling CO_2, the correction factor for temperature is estimated as the following:

$$CF_{[Temp]} = (T_{GCM}-T_B)/4.5$$

where T_B is temperature in the baseline year, T_{GCM} is temperature under changing climate respectively. The 4.5 value may vary with commodity. However, since the data on this was not available, a value of 4.5 was used. Thus the combined correction factor would be as follow:

$$CF = 1+ [b\mathrm{Ln}(C/C_0)*(T_{GCM}-T_B)/4.5]$$

Mean monthly rainfall of the province (step 3) was calculated as weighted-mean. This was calculated based on fraction of rice growing area in a province lying in rainfall regions. The methodology used to divide Cambodia into several rainfall regions is described in Chapter 2. Flow diagram of the analysis is presented in Figure 3.3.

In many developed countries, the types of model used to evaluate the vulnerability of agriculture sectors to climate change are mechanistic-based models (deterministic approach). However, these models require a considerable inputs where this is the main constraint faced by most of developing countries. Therefore, in this analysis a simplified approach (empirical-based models) was used.

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[1] The impact of increasing temperature and doubling CO_2 on winter wheat was conducted using mechanistic model in which water, nutrition , pest and disease were not limiting factors.

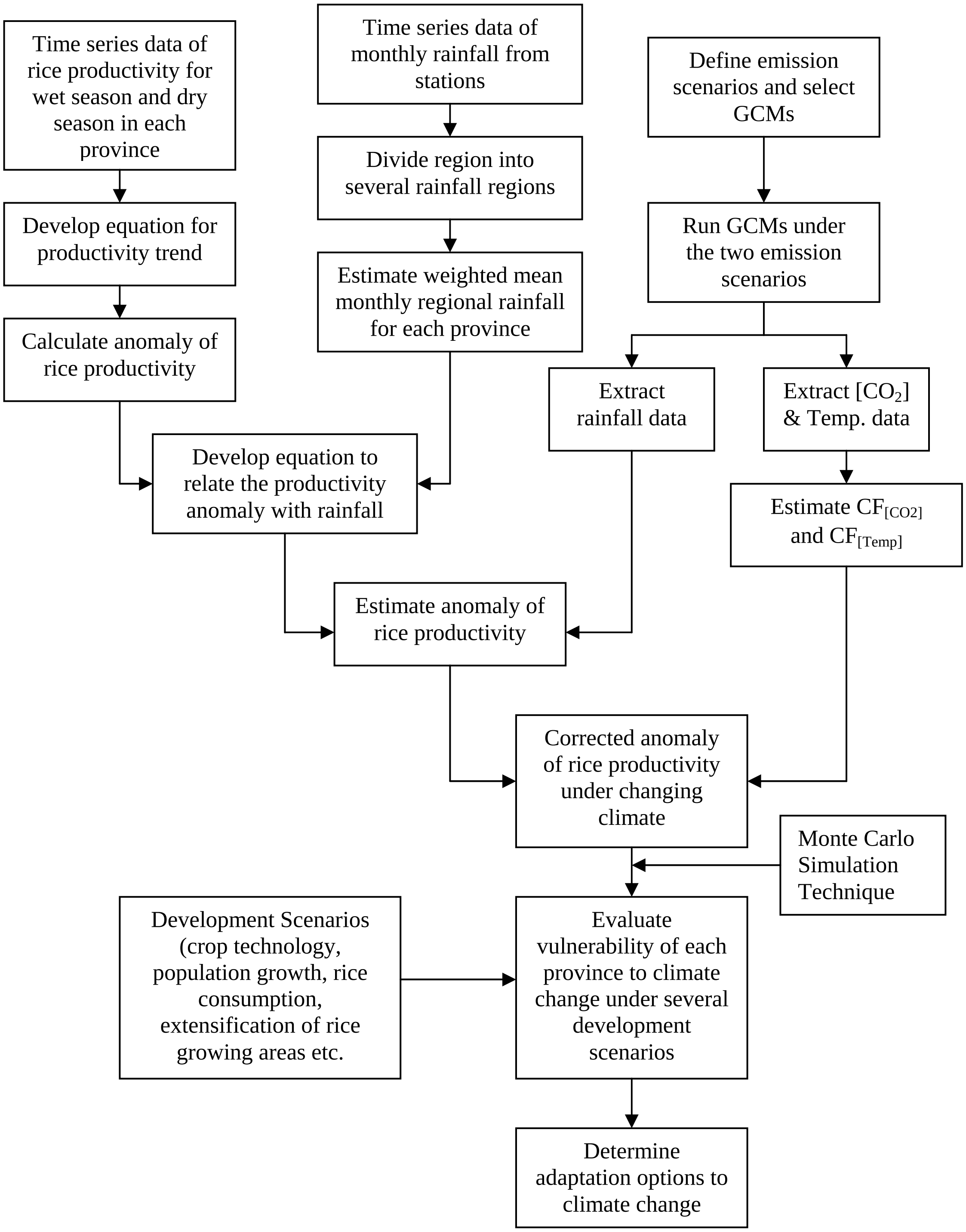


Figure 3.3: Steps of Analysis for Assessing Vulnerability and Defining Adaptation Options of Agricultural Sector to Climate Change

III.3.2. Results of Analysis

Historical Pattern of Yield Trend and Yield Anomaly. In most of the major rice growing areas, the rate of yield increase of dry season rice is faster than that of wet season rice. A significant change in rate was observed after 1993 (Figure 3.4) because political stability had been achieved, and this created good opportunity for the country to develop their economy. However, in some minor rice growing areas such as Preah Vihear, Stung Treng, Rattanakiri and Mondulkiri, the increase in rice productivity remains low (See Appendix 3.7.1 for detail).

In the four main rice growing areas, it was found that the yield anomaly of wet season rice was found to be positively correlated with May rainfall while dry season rice was negatively correlated with March rainfall, except for Battambang (Figure 3.5). This indicates that variability of yield anomaly for WS rice can be explained partly by May rainfall, where May rainfall is very important for supporting the vegetative growth of WS rice. Growing season for the wet season rice is from May to October. Normally, farmers start planting WS rice in May. Thus water shortage occurring during this month (early stage of development or vegetative growth) may affect yield significantly since during this period rice is sensitive to water shortage. The growing season for DS rice is from November to April. Harvesting commonly occurs in April and May. High rainfall in March may have a negative impact on rice yield since during this month crop requires more radiation for seed filling and ripening.

Yield Anomaly under Changing Climate. In general the mean yield anomaly of wet season rice in the four provinces would be more than zero while those of dry season rice would be less and equal to zero. These results suggested that under elevated CO_2 either under scenario SRESA2 or SRESB1, yields of WS rice might increase above that of dry season rice (Figure 3.6). In addition, mean anomaly of WS rice tended to increase from about 0 in 2000 to about 0.1 or 0.2 t/ha in 2050 or 2100 (Figure 3.6). However, there is a chance that under changing climate, variability of yield would increase as indicated by the wider confidence interval of the anomaly. In most cases confidence intervals of yield anomaly in year 2000 are narrower than those in year 2025, 2050 and 2100, in particular for wet season rice in Battambang, Prey Veng and Kampong Cham. Therefore, rice production in these three provinces under changing climate would be more variable than the current condition.

Referring to Figure 3.2, most of production lost was due to flood occurrences. On the other hand, under elevated CO_2 it has been indicated that rainfall in low land areas (main rice growing areas) would increase quite significantly (see Chapter II). Therefore, under changing climate, frequency and intensity of flood occurrence may increase which in turn would cause serious damage to rice crops exposing farmers to higher risk and particularly in relation to wet season rice production. Therefore, research on developing varieties resistant to flood would be very important.

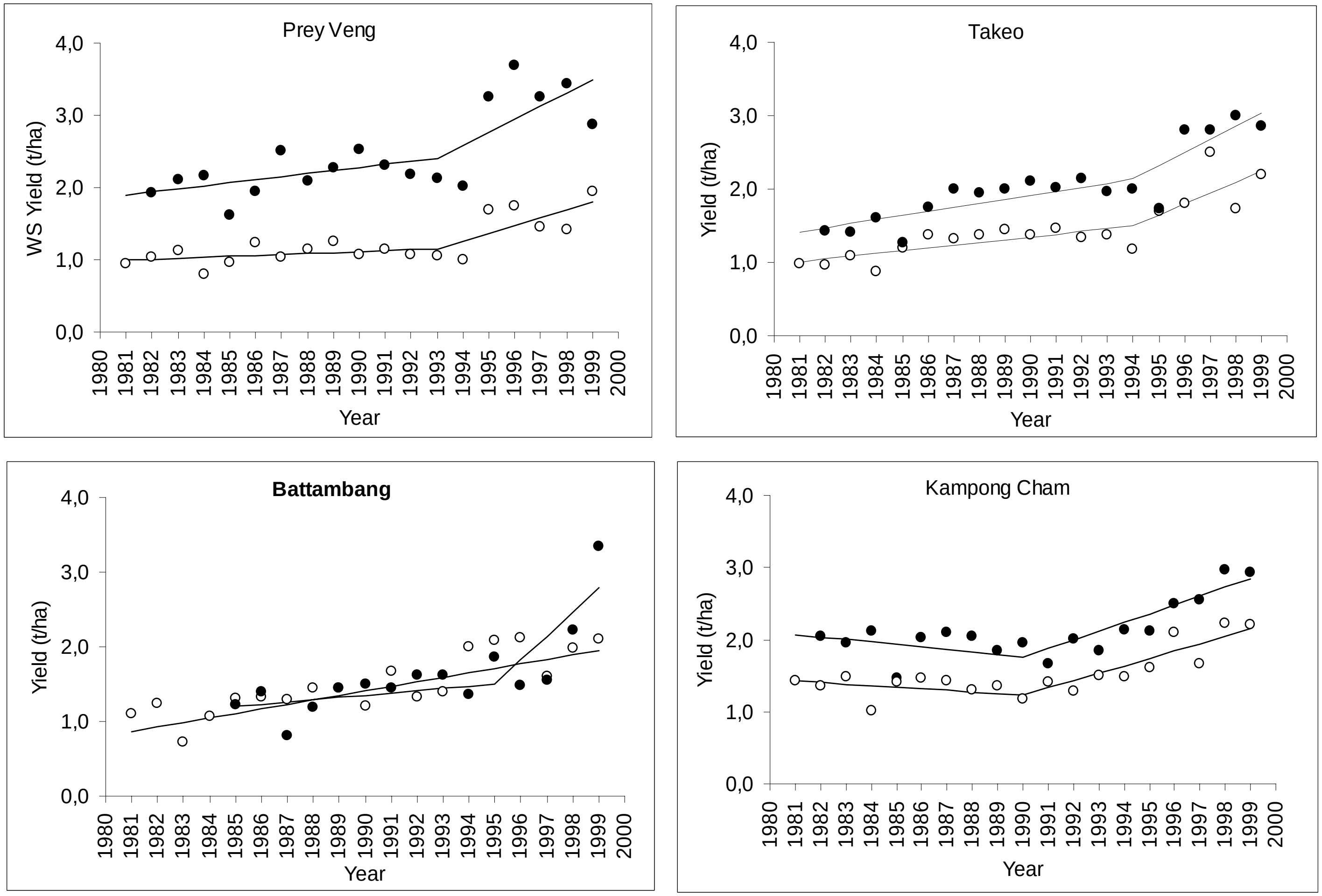


Figure 3.4: Yield Trend in Major Rice Growing Areas of Cambodia

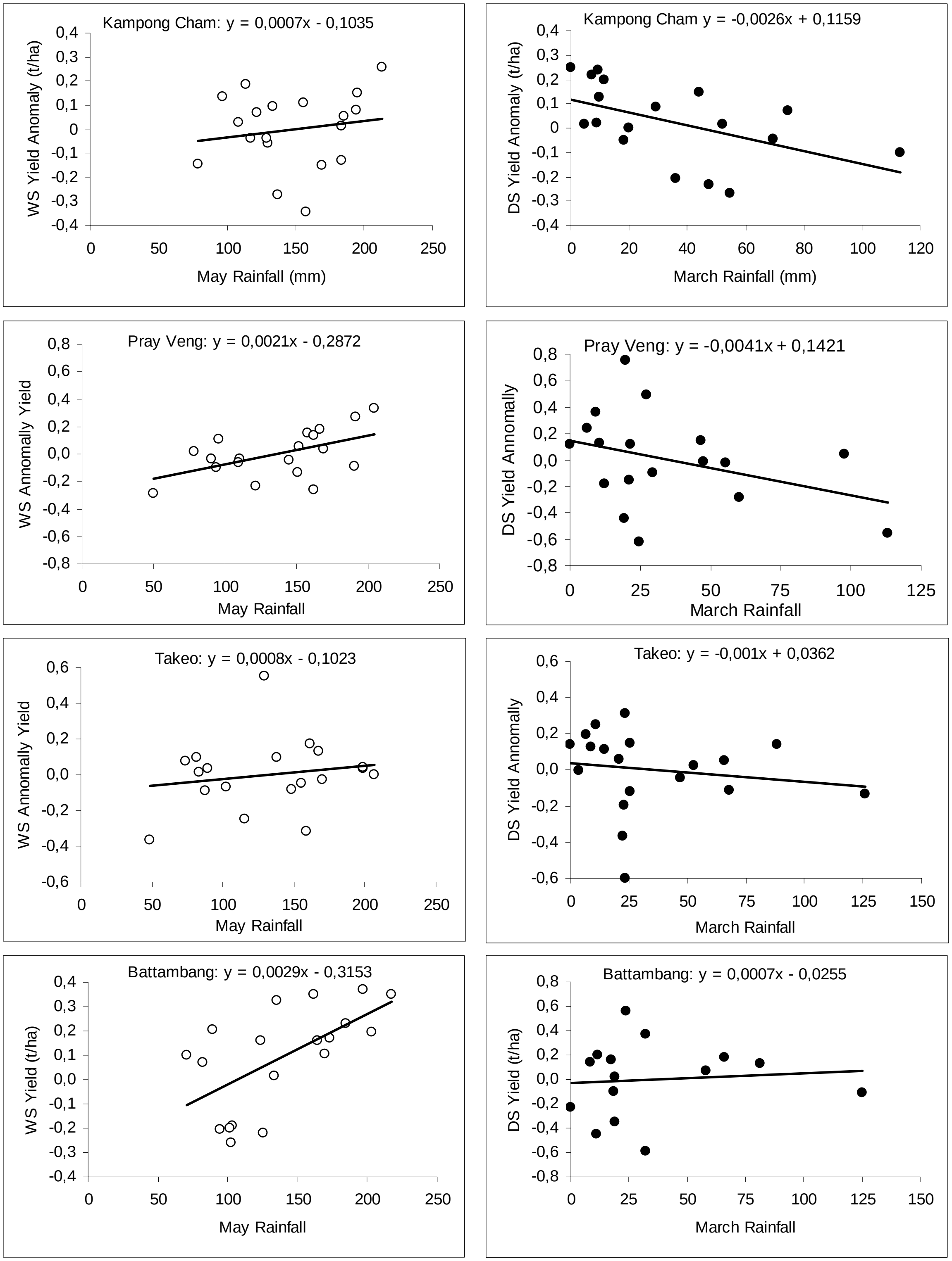
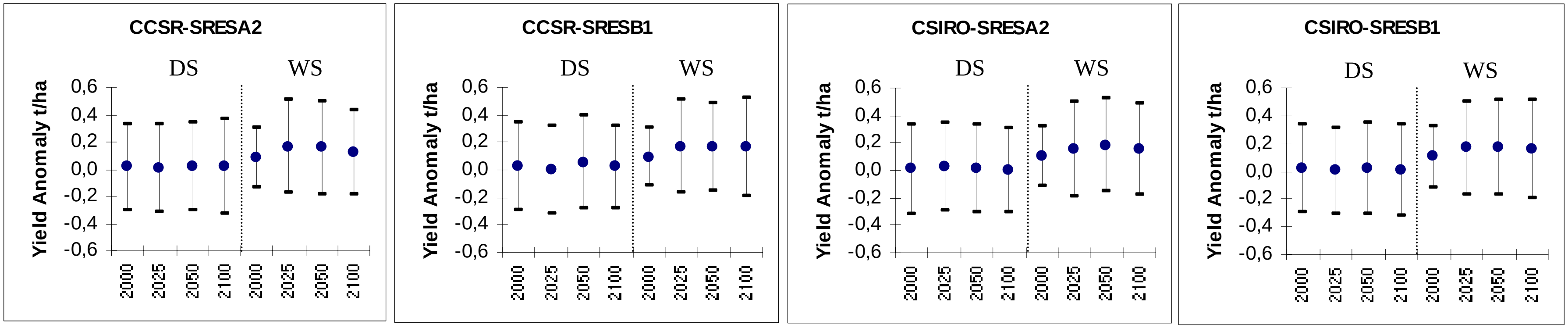


Figure 3.5: Relationship between Yield Anomaly of Wet Season Rice and May Rainfall and between Yield Anomaly of Dry Season Rice and March Rainfall

(a) Battambang



(b) Prey Veng

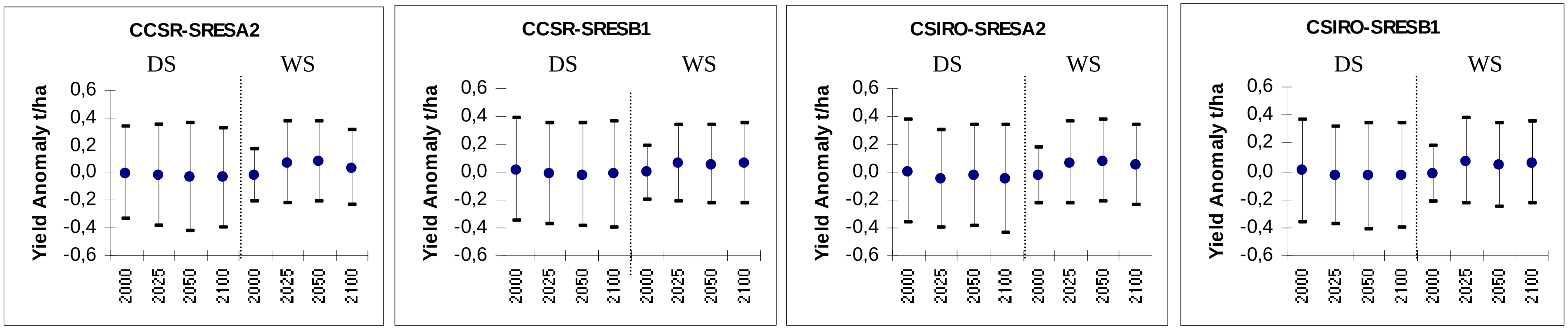
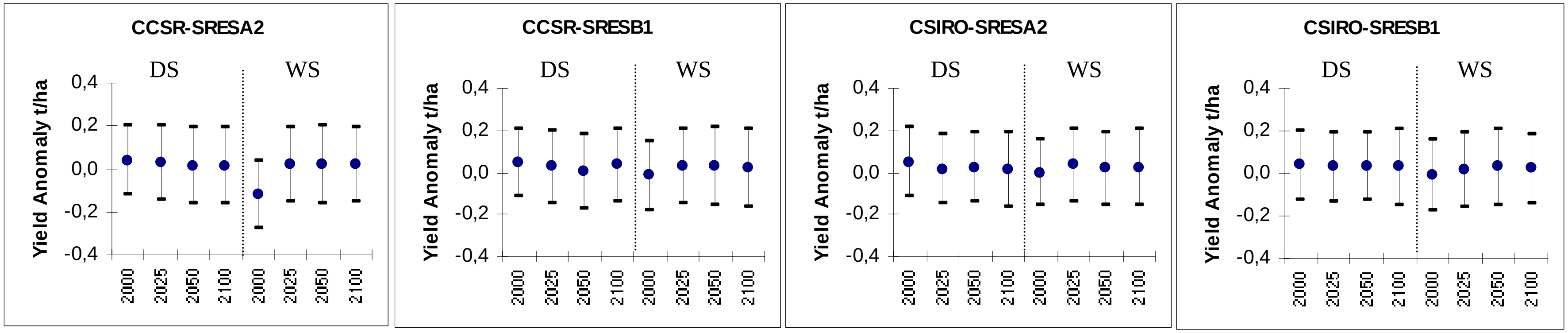


Figure 3.6: Yield Anomaly for Dry Season and Wet Season Rice under two GCM Models and two Emission Scenarios at a) Battambang and b) Prey Veng

(c) Kampong Cham



(d) Takeo

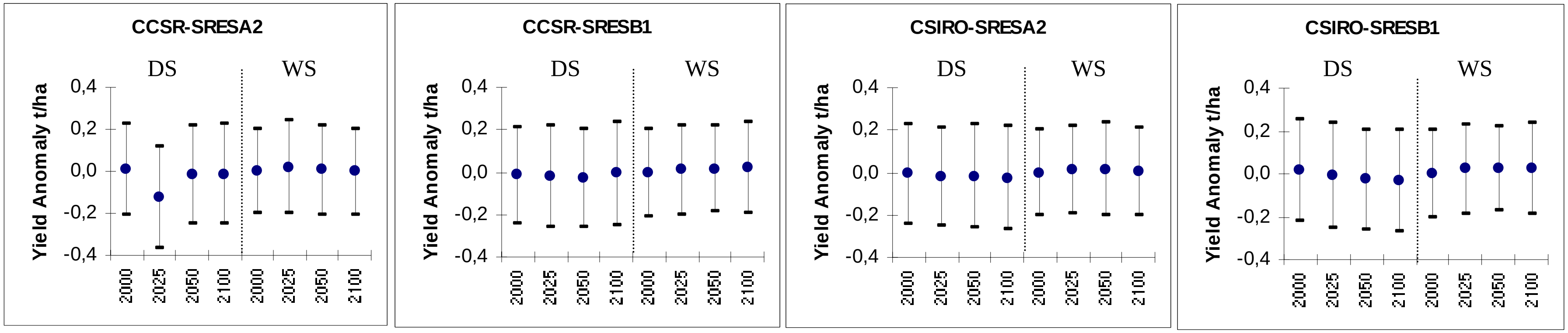


Figure 3.6 (cont.): Yield Anomaly for Dry Season and Wet Season Rice under two GCM Models and two Emission Scenarios at c) Kampong Cham and d) Takeo

As in the methodology described in the previous sub-sector, this study used a single climatic variable to estimate yield anomaly, i.e. rainfall. This may not fully represent the impact of climate change. For future studies, the use of deterministic approach is therefore strongly recommended. The possible increase in yield in the future could be estimated from the use of crop growth inputs such as fertilizer, pesticide and other environmental factors. In this study the increase in yield in the future was based on historical yield trend, potential yield of the rice varieties and government projection on yield increment. The final estimate of yield was then corrected by the increase of CO_2 and temperature.

Impact of Climate Change on Rice Production. After estimating the possible change in yield under future climate, rice production of these four provinces was estimated by multiplying the yield with the expected planted area. The planted area in year 2025, 2050 and 2100 was estimated based on government target. In 2000, it was shown that rice production in Kampong Cham was insufficient to meet the demand. This resulted in a deficit of about 100,000 tonnes, while in other three provinces, rice production exceeded demand (Figure 3.7; see Appendix 3.7.2 for detail).

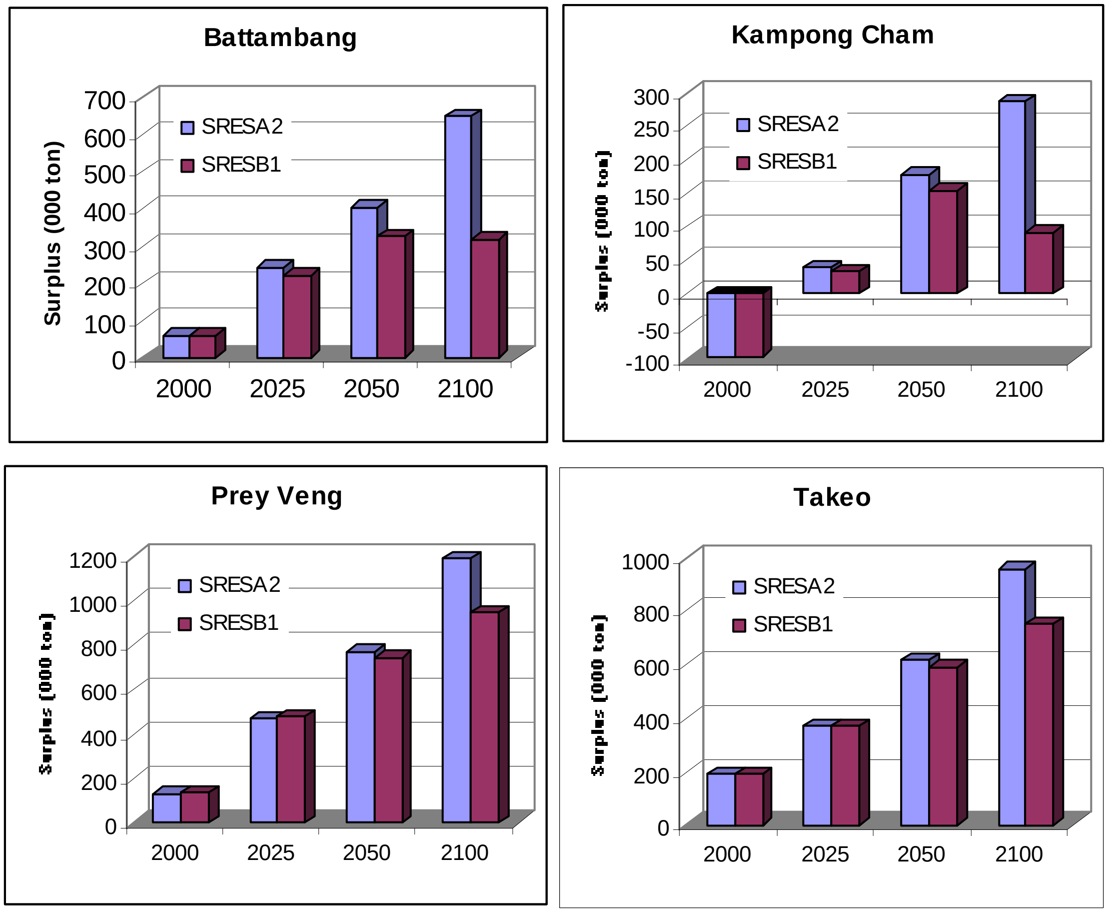


Figure 3.7: Surplus of Rice Production in the four Provinces under two GCM Models and two Emission Scenarios

The impact of climate change on rice production in Kampong Cham and Battambang under SRESA2 and SRESB1 is very different, in particular for 2100. In Prey Veng and Takeo, the difference was not as big as in Kampong Cham and Battambang (Figure 3.7; see Appendix 3.7.2 for detail). This is because in Kampong Cham and Battambang, the impact of elevated CO_2 on rainfall under SRESA2 is very different from that under SRESB1. Higher production in all provinces under SRESA2 is primarily due to a greater increase in CO_2 concentrations leading to higher yields. In 2100, CO_2 concentration in the atmosphere is predicted to be 825 ppm under SRESA2 compared with 550ppm under SRESB1. As this study used a stochastic approach where some of determinant factors in crop growth and development were not taken into account, further study for verification is required.

Furthermore, the contribution of these four provinces to meet national demand was evaluated. It was suggested that in 2025, rice production from these four provinces can meet 56% of the national demand and increasing to 67% in 2050 under SRESA2 scenario and 65% under SRESB1 scenario (Table 3.4; see Appendix 3.7.3 for detail). In 2100, it was found that under emission scenario SRESA2 contribution of these four provinces to the total national demand is almost the same as in 2050 while under SRESB1 it is lower.

Table 3.4: Contribution of the four Provinces to National Rice Demand (%)

	SRESA2		SRESB1	
Year	**CSIRO**	**CCSR**	**CSIRO**	**CCSR**
2000	41	41	41	41
2025	56	56	56	56
2050	67	67	65	65
2100	66	65	53	53

III.4. Adaptation Options

The impact of climate change on rice production in Cambodia would not be substantial if the Government could meet the agriculture development plan. Study in the four provinces indicated that from 2025 to 2100, rice production would exceed demand, if the rice productivity could be increased by about 1t/ha every 25 years from the current productivity.

The contribution of these four provinces to internal demands also tend to increase. Programs than can be implemented to increase the rice productivity include:

1. Improvement of genetic or development of new high yielding varieties;
2. Improvement of crop management and cultural practices;
3. Development of capacity to adapt to current extreme climate such as development of early warning system to extreme climate, development maps showing the provinces of rice growing areas prone to flood and drought;
4. Development of irrigation facilities in many parts of low land areas;
5. Increasing planting index in suitable areas; and
6. Diversification of foods.

III.5. Conclusion and Recommendations

Yield anomaly of wet season rice was positively correlated with May rainfall while dry season rice was negatively correlated with March Rainfall. Positive correlation for WS rice is expected since water shortages that occur during May (early stage of development or vegetative growth for WS rice) may reduce yield significantly. Negative correlation for DS rice is expected since high rainfall in March may give negative impact to rice yield. During this month crop requires more radiation for seed filling and ripening.

In general the mean yield anomaly of wet season rice in the four provinces under changing climate would be more than zero while those of dry season rice would be less than or equal to zero. There is a chance that under changing climate, rice yield in some provinces would be more variable than current conditions due to the increase in flood frequency and intensity, in particular in rice growing areas surrounding Tonle Sap Lake and the Mekong River.

Rice production in Battambang, Prey Veng and Takeo at present exceeds demand, while at Kampong Cham there is a deficit of about 100,000 tons. Under changing climate, rice production of the four provinces exceed the demand. In 2025, rice production predictions from these four provinces suggest that 56% of the national demand can be met and increasing in 2050 to 67% of national demand under SRESA2 scenario and 65% under SRESB1 scenario. In 2100, under SRESA2 the contribution of these four provinces to the total national demand is predicted to be similar to that in 2050 while under SRESB1 predictions are lower.

As this study used a stochastic approach in evaluating the impact of climate change in rice yield, some of determinant factors in crop growth and development are not taken into account. Further studies for verification are therefore recommended. The use of a deterministic approach would allow the capture of more factors that contribute to variability of yield.

III.6. REFERENCES

Gourdiaan, J and Unsworth, M.H. 1990. Implication of Increasing Carbon Dioxide and Climate Change for Agricultural Productivity and Water Resources. In *Impact of Carbon Dioxide, Trace Gases, and Climate Change on Global Agriculture*. ASA Special Publication No 53. American Society of Agronomy, p:111-130.

Kingdom of Cambodia, 2001. *Draft Second Five Year Socioeconomic Development Plan 2001-2005*, p.111-153.

MAFF. 1993. *Bulletin of Agricultural Statistics and Studies*, No 1. Department of Planning and Statistics, pp. 3-18.

MAFF. 1993. *Bulletin of Agricultural Statistics and Studies*, No 4. Department of Planning and Statistics, 40p.

MAFF. 1994. *Bulletin of Agricultural Statistics and Studies*, No.5. Department of Planning and Statistics, 39p.

MAFF. 1994. *Bulletin of Agricultural Statistics and Studies*, No.8. Department of Planning and Statistics, 33p.

MAFF. *1995 Agricultural Statistics*. Department of Planning and Statistics, 71p.

MAFF. *1996-97 Agricultural Statistics*. Department of Planning and Statistics, 87p.

MAFF. *1998-99 Agricultural Statistics*. Department of Planning and Statistics, 90p.

MAFF. *1999-2000 Agricultural Statistics*. Department of Planning, Statistics and International Cooperation, 81p.

MAFF. 2001. *Report No 358/038: Summary of Agricultural Activities* (15.01.2001). 13p.

MAFF. 1999. *Agriculture Development Plan. Long, Medium and Short Term, 1999-2010*. 20p.

Men, S., Edwin, J., Ouk, M. 1999. *Rice Varieties Released by the Cambodian Varietal Recommendation Committee*. Cambodia-IRRI-Australia Project. Cambodia.

Ministry of Planning. 2000. *General Population Census of Cambodia 1998, Analysis of Census Results, Report 6, Population Projections 2001-2021*. National Institute of Statistics, pp. 16-23. Phnom Penh, Cambodia.

Ministry of Planning. 2001. *Cambodia Statistical Yearbook 2000*. National Institute of Statistics, pp.79-107. Phnom Penh, Cambodia.

Ministry of Environment. 1994. Cambodia: First State of the Environment Report, pp.40.

Nisbett, H.J., and Helers, K. 1996. *Rice in the Cambodian Economy: Past and Present, Rice Production in Cambodia*. Cambodia-IRRI-Australia Project.

Squire, G.R. and Unsworth, M.H. 1988. *Effects of* CO_2 *and Climatic Change on Agriculture*. Report to the UK Department of Environment, University of Nottingham, United Kingdom.

III.7. APPENDIX

Appendix 3.7.1: Annual Growth Rate of Rice Yield and Harvested Area by Province

No	Province	WSYield, %	DSYield, %	WSHarvs., %	DSHarvs., %
1	Phnom Penh	1.17	0.63	3.66	2.95
2	Kandal	2.00	2.65	-4.62	3.32
3	Kampong Cham	2.64	2.34	1.75	3.42
4	Svay Reng	2.42	2.49	2.45	17.70
5	Prey Veng	3.22	3.40	1.24	2.12
6	Takeo	4.20	4.07	2.77	3.90
7	Kampong Thom	2.96	4.03	0.08	-0.02
8	Siem Reap	1.44	1.65	1.46	2.93
9	Battambang	4.15	5.77	-4.18	2.11
10	Banteay Meanchey	2.27	1.49	1.74	-17.84
11	Pursat	3.01	7.95	1.69	0.92
12	Kampong Chhnang	2.23	2.32	4.92	4.31
13	Sihanoukville	1.49	0.00	-2.69	0.00
14	Kampot	2.20	1.46	1.04	4.25
15	Koh Kong	1.44	0.00	1.61	0.00
16	Kampong Speu	3.78	4.22	1.09	-4.62
17	Preah Vihear	0.90	0.00	6.66	0.00
18	Stung Treng	-0.62	0.00	2.43	0.00
19	Rattanakiri	0.56	0.00	1.75	0.00
20	Mondoulkiri	0.66	0.00	4.34	0.00
21	Kratie	1.41	1.50	1.22	1.38
22	Krong Kep	3.20	0.00	28.22	0.00
	Average	**2.12**	**2.09**	**2.67**	**1.22**

Source: Ministry of Agriculture Forestry and Fisheries (1993-2000)

Appendix 3.7.2: Projection of Rice Production, Consumption and Demand, Population, Yield and Planting Area

Description	**Unit**	**CCSR-SRESA2**				**CCSR-SRESB1**			
		2000	**2025**	**2050**	**2100**	**2000**	**2025**	**2050**	**2100**
Battambang									
Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
Population	Million	0.79	1.04	1.29	1.74	0.79	1.04	1.29	1.74
Demand	Mtonne	0.19	0.21	0.23	0.31	0.19	0.21	0.23	0.31
Yield-DS	t/ha	1.80	4.07	6.44	8.85	1.76	4.07	6.26	7.28
Yield-WS	t/ha	2.08	3.73	4.98	6.96	2.08	3.72	4.82	5.74
Planting Area-DS	Mha	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Planting Area-WS	Mha	0.2000	0.2020	0.2040	0.2061	0.2000	0.2020	0.2040	0.2061
Production	Mtonne	0.2511	0.4547	0.6131	0.8658	0.2505	0.4533	0.5936	0.7145
Import/Export	Mtonne	0.0576	0.2223	0.3419	0.4661	0.0570	0.2209	0.3224	0.3148
Kampong Cham									
Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
Population	Million	1.61	2.12	2.62	3.54	1.61	2.12	2.62	3.54
Demand	Mtonne	0.39	0.42	0.47	0.64	0.39	0.42	0.47	0.64
Yield-DS	t/ha	3.10	4.08	6.44	8.90	3.10	4.09	6.24	7.32
Yield-WS	t/ha	2.23	3.57	4.84	6.85	2.22	3.58	4.70	5.61
Planting Area-DS	Mha	0.0350	0.0354	0.0357	0.0361	0.0350	0.0354	0.0357	0.0361
Planting Area-WS	Mha	0.1730	0.1747	0.1765	0.1782	0.1730	0.1747	0.1765	0.1782
Production	Mtonne	0.2973	0.4621	0.6494	0.9237	0.2958	0.4618	0.6313	0.7581
Import/Export	Mtonne	-0.0953	0.0341	0.1716	0.2576	-0.0968	0.0338	0.1506	0.0862
Prey Veang									
Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
Population	Million	0.95	1.17	1.40	1.80	0.95	1.17	1.40	1.80
Demand	Mtonne	0.23	0.23	0.25	0.32	0.23	0.23	0.25	0.32
Yield-DS	t/ha	3.00	4.05	6.40	8.84	3.02	4.06	6.22	7.26
Yield-WS	t/ha	1.75	3.62	4.89	6.84	1.76	3.61	4.72	5.65
Planting Area-DS	Mha	0.0600	0.0606	0.0612	0.0618	0.0600	0.0606	0.0612	0.0618
Planting Area-WS	Mha	0.2450	0.2475	0.2499	0.2524	0.2450	0.2475	0.2499	0.2524
Production	Mtonne	0.3646	0.6842	0.9685	1.3641	0.3677	0.6839	0.9355	1.1247
Import/Export	Mtonne	0.1338	0.4501	0.7174	1.0405	0.1368	0.4498	0.6843	0.8011
Takeo									
Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
Population	Million	0.79	1.04	1.29	1.74	0.79	1.04	1.29	1.74
Demand	Mtonne	0.19	0.21	0.23	0.31	0.19	0.21	0.23	0.31
Yield-DS	t/ha	3.00	4.04	6.40	8.81	3.00	4.04	6.20	7.26
Yield-WS	t/ha	2.40	3.56	4.82	6.80	2.41	3.56	4.68	5.60
Planting Area-DS	Mha	0.0600	0.0606	0.0612	0.0618	0.0600	0.0606	0.0612	0.0618
Planting Area-WS	Mha	0.1900	0.1919	0.1938	0.1958	0.1900	0.1919	0.1938	0.1958
Production	Mtonne	0.3818	0.5571	0.7951	1.1254	0.3824	0.5562	0.7720	0.9276
Import/Export	Mtonne	0.1890	0.3492	0.5632	0.8125	0.1896	0.3692	0.5917	0.7538
Total Production	Mtonne	**1.2948**	**2.1581**	**3.0262**	**4.279**	**1.2963**	**2.1553**	**2.9324**	**3.5249**

Appendix 3.7.2 (cont.): Projection of Rice Production, Consumption and Demand, Population, Yield and Planting Area

Description	**Unit**	**CSIRO-SRESA2**				**CSIRO-SRESB1**			
		2000	**2025**	**2050**	**2100**	**2000**	**2025**	**2050**	**2100**
Battambang									
Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
Population	Million	0.79	1.04	1.29	1.74	0.79	1.04	1.29	1.74
Demand	Mtonne	0.19	0.21	0.23	0.31	0.19	0.21	0.23	0.31
Yield-DS	t/ha	1.79	4.07	6.42	8.85	1.81	4.08	6.25	7.30
Yield-WS	t/ha	2.09	3.70	5.00	7.00	2.09	3.72	4.85	5.76
Planting Area-DS	Mha	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Planting Area-WS	Mha	0.2000	0.2020	0.2040	0.2061	0.2000	0.2020	0.2040	0.2061
Production	Mtonne	0.2518	0.4504	0.6161	0.8706	0.2522	0.4534	0.5978	0.7171
Import/Export	Mtonne	0.0583	0.2412	0.4051	0.6486	0.0587	0.2210	0.3266	0.3174
Kampong Cham									
Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
Population	Million	1.61	2.12	2.62	3.54	1.61	2.12	2.62	3.54
Demand	Mtonne	0.39	0.42	0.47	0.64	0.39	0.42	0.47	0.64
Yield-DS	t/ha	3.10	4.08	6.45	8.89	3.09	4.10	6.28	7.30
Yield-WS	t/ha	2.24	3.58	4.83	6.84	2.24	3.56	4.70	5.60
Planting Area-DS	Mha	0.0350	0.0354	0.0357	0.0361	0.0350	0.0354	0.0357	0.0361
Planting Area-WS	Mha	0.1730	0.1747	0.1765	0.1782	0.1730	0.1747	0.1765	0.1782
Production	Mtonne	0.2973	0.4621	0.6494	0.9237	0.2977	0.4605	0.6324	0.7563
Import/Export	Mtonne	-0.0953	0.0390	0.1774	0.2866	-0.0949	0.0325	0.1546	0.0903
Prey Veang									
Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
Population	Million	0.95	1.17	1.40	1.80	0.95	1.17	1.40	1.80
Demand	Mtonne	0.23	0.23	0.25	0.32	0.23	0.23	0.25	0.32
Yield-DS	t/ha	3.00	4.03	6.41	8.82	2.99	4.08	6.23	7.27
Yield-WS	t/ha	1.74	3.60	4.89	6.87	1.76	3.64	4.75	5.66
Planting Area-DS	Mha	0.0600	0.0606	0.0612	0.0618	0.0600	0.0606	0.0612	0.0618
Planting Area-WS	Mha	0.2450	0.2475	0.2499	0.2524	0.2450	0.2475	0.2499	0.2524
Production	Mtonne	0.3645	0.6814	0.9683	1.3678	0.3662	0.6889	0.9413	1.1267
Import/Export	Mtonne	0.1336	0.4706	0.7729	1.1880	0.1354	0.4782	0.7459	0.9470
Takeo									
Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
Population	Million	0.79	1.04	1.29	1.74	0.79	1.04	1.29	1.74
Demand	Mtonne	0.19	0.21	0.23	0.31	0.19	0.21	0.23	0.31
Yield-DS	t/ha	3.01	4.04	6.40	8.82	3.00	4.03	6.21	7.23
Yield-WS	t/ha	2.41	3.56	4.82	6.81	2.41	3.56	4.65	5.59
Planting Area-DS	Mha	0.0600	0.0606	0.0612	0.0618	0.0600	0.0606	0.0612	0.0618
Planting Area-WS	Mha	0.1900	0.1919	0.1938	0.1958	0.1900	0.1919	0.1938	0.1958
Production	Mtonne	0.3836	0.5562	0.7960	1.1272	0.3827	0.5565	0.7691	0.9250
Import/Export	Mtonne	0.1908	0.3691	0.6157	0.9534	0.1899	0.3694	0.5888	0.7511
Total Production	Mtonne	1.2971	2.15	3.0298	4.2894	1.2988	2.1592	2.9406	3.5252

Appendix 3.7.3: Projection of National Rice Consumption and Demand, Population and Contribution of Battambang, Kampong Cham, Prey Veng and Takeo to National Rice Demand

Description	Unit	CSIRO-SRESA2				CSIRO-SRESB1			
		2000	**2025**	**2050**	**2100**	**2000**	**2025**	**2050**	**2100**
National Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
National Population	Million	13.10	19.32	25.22	36.68	13.10	19.32	25.22	36.68
National Rice Demand	Mtonne	3.20	3.86	4.54	6.60	3.20	3.86	4.54	6.60
Rice Production of the 4 Provinces	Mtonne	1.30	2.15	3.03	4.37	1.30	2.16	2.94	3.53
Contribution of the 4 Province to National Demand	%	41	56	67	66	41	56	65	53
		CCSR-SRESA2				**CCSR-SRESB1**			
National Rice Consumption	kg/cap	244	200	180	180	244	200	180	180
National Population	Million	13.10	19.32	25.22	36.68	13.10	19.32	25.22	36.68
National Rice Demand	Mtonne	3.20	3.86	4.54	6.60	3.20	3.86	4.54	6.60
Rice Production of the 4 Provinces	Mtonne	1.30	2.16	3.03	4.28	1.30	2.16	2.93	3.52
Contribution of the 4 Province to National Demand	%	41	56	67	65	41	56	65	53

IV. VULNERABILITY AND ADAPTATION FOR FORESTRY

IV.1. Introduction

Cambodia is a tropical country that has a land area of about 10.6 million hectares with approximately 58 percent of the area covered by forest. During the 20 years of civil war forest activities were substantially reduced, and forest resources and forest lands were significantly depleted and degraded. A large portion of these deteriorated forestlands was converted to other types of land use.

The forestry sector plays an important role in the Cambodian economy. It is estimated that Cambodian forests have a growing stock of about 1,484 millions m^3. Legal annual wood extraction rates amount to about 1.5 millions m^3. With wood sale price of 200 USD/m^3, this sector contributes approximately 10% of National GDP or 100 million US$ (about 1/3 of the total budget revenue, No11, 1998). However, due to increasing population, agricultural development, increasing fuelwood demands, construction wood demands and shifting cultivation, the forest growing stock may soon be adversely affected.

According to the Ministry of Agriculture, Forestry and Fisheries (MAFF), Cambodian forests can be divided into dry-land forest and edaphic forest. In the period between 1973 and 1993, approximately 1.4 million ha of the forests were deforested. The annual rate of deforestation has since then been on the increase. The annual rate of deforestation between 1973 and 1993 was 0.6% (about 71,000 ha/year) and in the period of 1993 to 1998 it increased to 0.8% (about 88,000ha/year). Some deforested areas were converted into agricultural land and a signification portion of this area was so severely degraded that it has been re-classified as shrub lands rather than forest. In 1998, total area of shrub lands was about 2 million hectares (MAFF and World Bank, 1999).

Climate change may accelerate the process of forest degradation due to the increase in erosion as a result of increasing rainfall. The increase in temperature due to elevated CO_2 in tropical countries under changing climate might not have a significant impact on forest (IPCC, 1996). However, the change in soil water availability (caused by combined effects of changes in temperature and rainfall) would have a significant impact on biomass production and forest classification (Whetton and Rutherford, 1994). Studies in India showed that net primary productivity of teak plantation was significantly related to the precipitation effectiveness index (Achanta and Kanetkar, 1996). A projected depletion of soil moisture would likely cause teak productivity to decline from 5.40 m^3/ha to 5.07 m^3/ha. The productivity of moist deciduous forests also could decline from 1.8 m^3/ha to 1.5 m^3/ha. In Indonesia, based on Petterson Index, change of productivity depends on location and GCM model used. The change can be negative or positive (Boer et al., 1999). Since the forest sector has a significant role in the Cambodian economy, study on the evaluation of climate change impact on this sector is becoming very important.

The objective of this study is to evaluate the impact of climate change on Cambodian forest types based on Holdridge Life Zone Classification (US-CS, 1994).

IV.2. Forestry Sector in Cambodia

IV.2.1. Forest Classification of Cambodia

Many classification systems exist for humid tropical vegetation and a variety of these have been used to describe the vegetation of Cambodia in recent years. One system classified Cambodia's forest into three types, namely (World Bank/FAO/UNDP, 1996):

1. Dryland forests which consist of evergreen, coniferous, deciduous, mixed and secondary forests. Evergreen forest is a multistory forest consisting of more than 80% trees of evergreen species. The main species are *Dipterocarpus dyeri, D. corbatus, D. alalatus, Anisoptera cochinchinensis, Hopea adorata, H. pierrei, Roherea vulgaris, Syzysium spp*. Mixed forest is a forest which has a mixture of deciduous and evergreen species, where deciduous species represent more than 50% of the stand. Coniferous forest refer to Pines forest (mainly in Kirirom area) and deciduous forest refers to Dipterocarp forest. Most Dipterocarp species are fire resistant and have thick bark, such as *Dipterocarpus inticartus, D. obtisifolius, Shorea obtusa, Terminalia tomentosa*, etc. The last category is secondary forest/re-growth which refers to open forest with re-growth mostly after shifting cultivation.

2. Edaphic forests consist of flooded, flooded secondary and mangrove forests. Flooded forest refers to flooded forest around the Tonle Sap Lake, flooded secondary forest refers to flooded secondary forest with open canopy and regrowth after cultivation or cutting, and mangrove forest refers to mangrove forest (on tidal saline water) and rear mangrove forest.

3. Forest plantation that consists of rubber plantation, pine, eucalyptus, and teak (*Tectona grandis*).

In addition to the above categories, there are three other land uses categories. They are shrub land, bamboo and grassland. Shrub lands are dominated by woody species with maximum height of 5 meters at maturity. Bamboo is woody grass, mainly from tropical subfamily, i.e. *Bambusidae*. Grassland is infertile or degraded land where few trees or shrubs grows. Total area of these forests in 1998 is presented in Table 4.1.

Table 4.1: Forest Area by Type

Forest Type	Area (ha) in 1998
A. Dry Land Forest	**10,086,000**
Evergreen	4,094,000
Mixed & Coniferous	1,395,000
Deciduous	4,052,000
Secondary/Regrowth	545,000
B. Edaphic Forest	**428,000**
Mangrove	77,000
Flooded	351,000
Flooded secondary	
Total Forest (A+B)	**10,514,000**
C. Others	**2,108,000**
Forest plantation	85,000
Agro-Forestry	
Shrubland	2,023,000
Total (A+B+C)	**12,622,000**

Source: MAFF and World Bank (1999).

IV.2.2. Forest/Plantation Productivity

Productivity of Cambodian forests has been estimated to be about 0.3 m^3/ha/year (World Bank/FAO/UNDP, 1996). Using a cutting cycle of 35 years, total allowable cut would be about 10 m^3 per hectare or approximately 30% of total standard volume. This is Cambodian standard as established under Article 3 of the "Regulations on Forest Resources Exploitation".

According to the earlier field inventories and dendromatric analysis in Cambodia forests (FAO,1962; Legris and Blasco, 1972), volume over bark (VOB) of all living trees of more than 10 cm diameter is about 230 m^3/ha in the evergreen forests and only 60 m^3/ha in the deciduous forests, and 150 m^3/ha in mixed forest. The volume of "potentially available for cutting" (VAC) of all marketable tree above 40 cm diameter is 80 m^3/ha in the evergreen forests, 30 m^3/ha in deciduous forests and 60 m^3/ha in the mixed forests (Table 4.2, World Bank/FAO/UNDP, 1996).

Table 4.2: Type of Forest and Volume

Forest Type	VOC	VAC Total 40cm<Diam.	VAC Total1 40cm<Diam. <60cm	VAC Total2 Diam.>60cm	VAC Management	VAC, %
Evergreen	230	80	24	56	20	25
Deciduous	60	30	20	10	15	50
Mixed	150	60	18	42	15	25
Secondary	100	50	30	20	15	30

Source: FAO (1962) and Legris and Blasco (1972). Volume Over Bark (VOB) of free boles from stump or buttresses to crown point or first main branch of all living trees more than 10 cm diameter at breast height or above buttresses if they are higher; VAC: volume potentially available for cutting that is under bark of logs extracted from the forests.

Forest plantations in Cambodia are dominated by rubber plantations. These plantations have been considered as the main income cash crop for the national economy and activities that could absorb significant amounts of labor. At present, rubber plantations fall under the category of public enterprise, namely through the Rubber Development Company. However this company is also responsible for the small holder or individual rubber development in the whole country. In 1993, rubber production amounted to about 22,345 tonnes and in 1997 it increased to 43,323 tonnes. In the last five years, total new rubber plantations amounted to 3,386 ha while the mature plantations accounted for 1,385 ha (Department of Forestry and Wildlife, 1999).

IV.3. Assessment of Vulnerability of Cambodia's Forest to Climate Change

IV.3.1. Methodology

In this study, the GCM models used for the assessment are CCSR and CSIRO models with two emission scenarios, i.e. SRESA2 and SRESB1 (see Chapter II for detail). The main aspect being investigated was impact of climate change on Cambodian forest type, while its impact on forest productivity was not included due to unavailability of data for the analysis. Distribution of land cover of Cambodia based on Holdridge Life Zone Classification Model (US-CS, 1994) was employed. The Holdridge Model is a climate classification scheme that relates the distribution of major ecosystem complexes to the climate variable of bio-temperature, and mean annual precipitation (Table 4.3). The life zones are depicted by a series of hexagons in a triangular coordinator system.

Table 4.3: Rainfall and Temperature Regimes for Each Forest Type According to Holdridge Classification System (Ref. Holdridge 1967)

Holdridge Life Zone	Rainfall, mm	Temperature, °C
Rain Forest	4,000-8,000	from 12 to 24
Wet Forest-1	4,000-8,000	>24
Wet Forest-2	2,000-4,000	from 12 to 24
Moist Forest-1	2,000-4,000	>24
Moist Forest-2	1,000-2,000	from 12 to 24
Dry Forest-1	1,000-2,000	>24
Dry Forest-2	500-1,000	from 12 to 24
Very Dry Forest	500-1,000	>24
Thorn Steppe/Thorn Woodland	250-500	from 12 to 24
Thorn Woodland	250-500	>24
Desert Bush	125-250	from 12 to 24
Desert Bush	125-250	>24

Note: The highlighted is forest type in Cambodia according to Holdridge Classification System.

The analysis was carried out as follows. The first step was to identify forest type using the current classification system in each grid of GCM models. The second step was to classify forest according to Holdridge System based on interpolated observed climatic data in each grid. The third step was to match forest type between the current classification system and Holdridge System. The fourth step was to assess forest type in each grid under future climate conditions extracted from MAGICC-SCENGEN. The fifth step was to estimate percentage change of forest area from baseline. Percentage change of area from baseline conditions was estimated using the following equation:

$$\%Change = \frac{(Area\ under\ \ future\ condition - Area\ under\ current\ condition)}{Area\ under\ current\ condition} x100\%$$

IV.3.2. Results and Discussion

Using Holdridge System, forest type in Cambodia under current conditions could be classified into three, namely wet forest-2, moist forest-1 and -2, and dry forest-1 (hereafter, wet forest-2 and dry forest-1 are referred as wet forest and dry forest respectively). By overlaying Holdrigde forest type with the current forest type, it was found that evergreen can be found in all Holdridge's forest types, i.e. wet forest, moist forest, and dry forest (Table 4.4). This indicates that Holdridge System was not consistent with the current forest classification system. This is because the current system does not use bio-temperature, and mean annual precipitation as a basis for the classification. For the simplicity, the subsequent analysis only considers Holdridge Classification System.

Table 4.4 showed that total area of dry forest amounted to about 6.4 million ha, more than 50% of the total forest area. This suggests that most of Cambodian forest can be categorized as dry forest according to Holdridge Classification System. The area of wet and moist forests is almost equal, i.e. about 2.0 million ha.

Table 4.4: Classification of Cambodian Forest According to Holdridge System and its Relation with Current Forest Classification System under Current Climate

No	Forest Type under Holdridge System at Current Condition	Land Use Type under Current Condition	Total Area (ha)
1	Wet Forest	Evergreen, mixed, deciduous and grassland	2,067,855
2	Moist Forest-1	Evergreen, deciduous, mangrove, and forest plantation	1,146,395
3	Moist Forest-2	Evergreen	1,023,507
4	Dry Forest	Evergreen, mixed, deciduous, secondary forest, mangrove, forest plantation, inundated forest, shrub land, bamboo and grassland	6,361,137
	Total		**10,598,894**

The change in forest type due to climate change depends on type of GCM models and emission scenarios used in the analysis (Table 4.5 and 4.6; Figure 4.1 and 4.2). This is because the change in rainfall and temperature between the two GCM models and the two scenarios are different. Using the CCSR model, it was suggested that in 2050, the area of wet forest would decrease by about 11.5% in both emission scenarios (SRESA2 and SRESB1) and in 2100 it would further decrease by about 72% and 28% under SRESA2 and SRESB1 emission scenarios respectively (Table 4.5). Under SRESA2, the area of moist forest-1 would increase significantly from the present condition up to 100% in 2050 and 200% in 2100, while under SRESB1, the percent increase is much lower. Area of moist forest-2 may not change, but area of dry forest may decrease, but the decrease is not as much as that occurring in wet forest.

A similar pattern of change was also observed with CSIRO model (Table 4.6), but the magnitude of change was not as big as that in CCSR, except for moist forest-2. Under CSIRO model, the area of moist forest-2 would decrease by about 33% under SRESA2 and no change under SRESB1. As forest category under moist forest-2 only includes evergreen, there is a big potential that the area of evergreen forest would decrease quite significantly under changing climate.

Unwise use or mismanagement of the forest may enhance this change. In the period between 1973 and 1998, the total area deforested amounted to about 2.8 million ha (equivalent to decreasing rate of 2.1% per year or 100 thousand hectares per year; World Bank/FAO/UNDP, 1996; MAFF and World Bank, 1999).

The results of the analysis suggests that under changing climate the area of wet and dry forests may decrease while moist forest may increase. If deforestation rates can not be reduced, disappearance of certain forest types may occur.

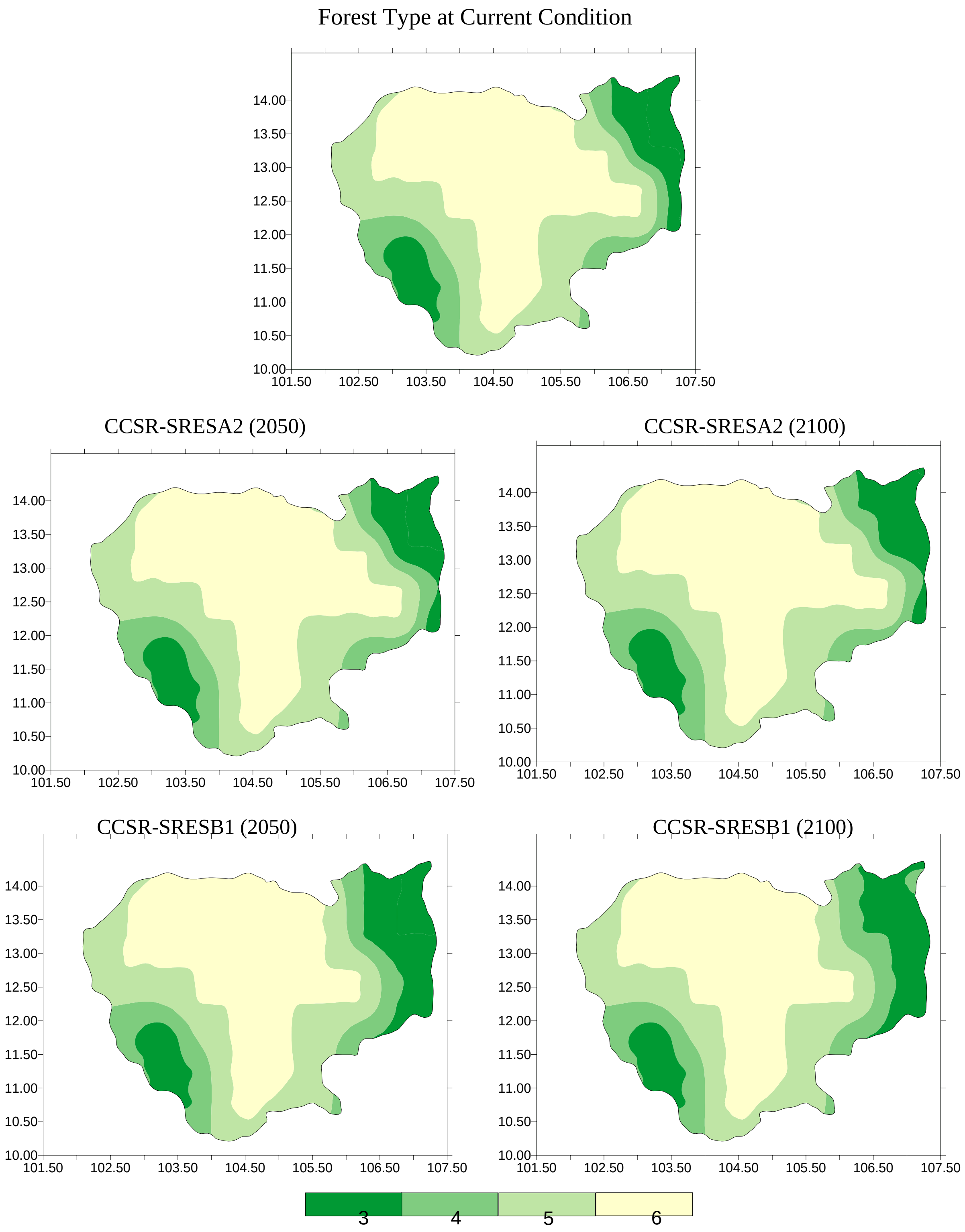
Table 4.5: Changes and Percent Change in Forest Area (Holdridge Life Zone Classification) due to Changing Climate under Emission Scenario SRESA2 and SRESB1 Using CCSR Model

Forest Type under Holdridge System	Baseline Forest Area (ha)	SRESA2 (ha and %)		SRESB1 (ha and %)	
		2050	2100	2050	2100
Wet Forest	2,067,855	1,829,488 (-11.5)	573,575 (-72.3)	1,829,488 (-11.5)	1,488,319 (-28.0)
Moist Forest-1	1,146,395	2,292,051 (99.9)	3,547,964 (209.5)	1,444,353 (26.0)	1,785,522 (55.8)
Moist Forest-2	1,023,507	1,023,507 (0.0)	1,023,507 (0.0)	1,023,507 (0.0)	1,023,507 (0.0)
Dry Forest	6,361,137	5,453,848 (-14.3)	5,453,848 (-14.3)	6,301,546 (-0.9)	6,301,546 (-0.9)
Total	**10,598,894**	**10,598,894**	**10,598,894**	**10,598,894**	**10,598,894**

Table 4.6: Changes and Percent Change in Forest Area (Holdridge Life Zone Classification) due to Changing Climate under Emission Scenario SRESA2 and SRESB1 Using CSIRO Model

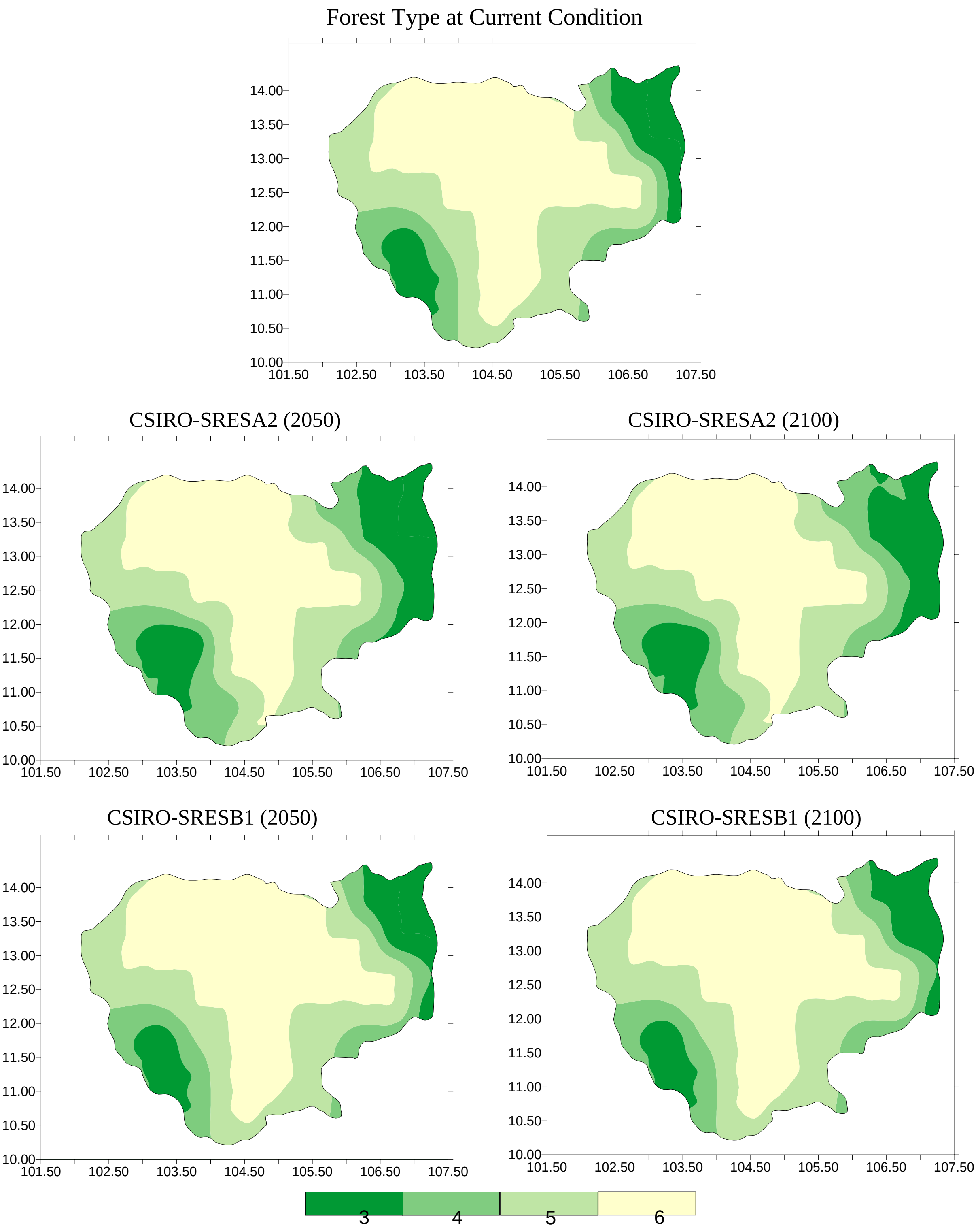
Forest type under Holdridge system	Baseline Forest area (ha)	SRESA2 (ha and %)		SRESB1 (ha and %)	
		2050	2100	2050	2100
Wet Forest	2,067,855	2,170,657 (5.0)	1,488,319 (-28.0)	1,829,488 (-11.5)	1,488,319 (-28.0)
Moist Forest-1	1,146,395	2,633,220 (129.7)	3,315,558 (189.2)	1,444,353 (26.0)	1,785,522 (55.8)
Moist Forest-2	1,023,507	682,338 (-33.3)	682,338 (-33.3)	1,023,507 (0.0)	1,023,507 (0.0)
Dry Forest	6,361,137	5,112,679 (-19.6)	5,112,679 (-19.6)	6,301,546 (-0.9)	6,301,546 (-0.9)
Total	**10,598,894**	**10,598,894**	**10,598,894**	**10,598,894**	**10,598,894**

As described in the previous section, each forest type contains many types of tree species. In evergreen forest for example, the dominant tree species are *Dipterocarpus dyeri*, *D. corbatus*, *D. Alalatus*, *Anisoptera cochinchinensis*, *Hopea adorata*, *H. pierrei*, *Roherea vulgaris*, and *Syzysium*, while the coniferous forest is dominated by Pines forest (mainly in Kirirom area) and deciduous forest is dominated by *Dipterocarpus inticartus*, *D. obtisifolius*, *Shorea obtusa*, *Terminalia tomentosa*. These species may be significantly affected by rainfall and temperature changes as indicated by studies in other countries. In India for example, net primary productivity of teak plantation was significantly related to the precipitation effectiveness index (Achanta and Kanetkar, 1996). A projected depletion of soil moisture would most likely cause teak productivity to decline from 5.40 m^3/ha to 5.07 m^3/ha. The productivity of moist deciduous forests could also decline from 1.8 m^3/ha to 1.5 m^3/ha. Therefore, future studies on the impact of climate change on forest biodiversity and forest productivity are necessary.



Note: 3 = wet forest, 4=moist forest-1, 5=moist forest-2 and 6=dry forest.

Figure 4.1: Cambodia Forest Classification According to Holdridge Life Zone Classification at Current Conditions (Mean of 1961-1990), and under Changing Climate (2050, and 2100) Using CCSR Models under both SRESA2 and SRESB1 Emission Scenarios



Note: 3 = wet forest, 4=moist forest-1, 5=moist forest-2 and 6=dry forest.

Figure 4.2. Cambodia Forest Classification According to Holdridge Life Zone Classification at Current Conditions (Mean of 1961-1990), and under Changing Climate (2050, and 2100) Using CSIRO Models under both SRESA2 and SRESB1 Emission Scenarios

IV.4. Adaptation Options

According to the Holdridge Classification System, under current climate conditions Cambodia's forests are dominated by a dry forest (60%), followed by wet forest (20%) and moist forest (20%). Under changing climate, the area of wet forest would decrease while moist forest would increase and dry forest would remain the same. This change indicated that forest productivity and biodiversity might also change. High rate of deforestation may accelerate the loss of forest biodiversity and reduce forest productivity due to the increase in human activities in the forest areas. In order to reduce the impact of climate change on the forest sector, the available options include:

1. *Forest Plantation Establishment*

Promotion of forest plantation establishment is important to relieve pressure on the natural forest. The optimal use of unproductive land for forest plantation establishment should be encouraged. Tree species used in the designated areas should match with socio-economic and biophysical conditions of the areas as well as global market. Therefore, maps of land quality index for tree plantations should be verified or established.

2. *Conservation of Protected Areas*

There is a need for establishment of appropriate legal and policy frameworks, protected area management plans, and an effective monitoring system. Strengthening law enforcement, and community participation in protected area management are also critical. Programmes for protecting critical wildlife habitats and for the expansion of species and forest communities, should also be enhanced in particular in the likely affected areas. Programmes to rehabilitate the protected forests also need to be promoted through enhanced natural regeneration techniques using native and exotic tree species.

3. *Improvement of Forest Resource Management*

The common goal of forest management is to achieve sustainable management through the utilization of forest resources in sustainable ways. Partially, this can be done through the promotion of improved silvicultural systems and techniques (such as reduced impact logging techniques) to forest concession holders.

IV.5. Conclusion and Recommendations

According to the Holdridge classification system, most of the forests in Cambodia can be classified as dry forest which covers about 60% of the total forest area, while wet and moist forest cover about 20% each. Under changing climate, the area of wet forest and dry forest will decrease while moist forest may increase.

The magnitude of change of forest area due to climate change depends on GCM model and emission scenarios used in the analysis. In this study, patterns of change of forest type due to climate change were similar in both GCM models, CCSR and CSIRO.

Further study on the impact of climate change on forest biodiversity and forest productivity needs to be carried out. Based on studies in other countries, it is possible that under changing climate, forest productivity of Cambodia's forests may change and some of species may disappear.

IV.6. REFERENCES

Achanta, A.N., and R. Kanetkar. 1996. *Impact of Climate Change on Forest Productivity: A Case Study of Kerala, India*. Paper presented at the Asia and Pacific Workshop on Climate Change Vulnerability and Adaptation Assessment, January 15-19, Manila, the Philippines.

Chea Vuthna, Kim Phalla, Meas Chandeth, and Hap Chanthea. 1998. *Economic and Financial Review*, No 11, 3Rd Quarter 1998. Ministry of Economy and Finance, 129 pp.

DoFW (Department of Forestry and Wildlife) of MAFF, 2000. *The Second Five-Year Plan for the Forestry Sector 2001-2005*.

MAFF, Secretariat for Forest Policy Reform, 1998. *Proceeds of Meeting to Brief the International and Senior Officials of the Royal Government of Cambodia on Forest Policy Reform*.

MAFF, General Directorate of Rubber Plantation, 2000. *Report on Exploitation and Production Situation of Rubber Planting in 9 Months Period of Year 2000*.

Mike Hulme, Elaine Barrow, Tom Wigley, Abel Centella, A.C. Chipanshi, Sahah Paper, and Steve Smith. 2000. *The Use of Simple Climate Model in Vulnerability and Adaptation Assessments: MAGICC and SCENGEN Workbook.* First order draft prepared for UNDP/GEF NCSP, 52 pp.

National Communications Support Programme. 2000. *Using a Climate Scenario Generator in Vulnerability and Adaptation Assessments: MAGICC and SCENGEN Version 2.4 Workbook*. 62pp.

Ravindranath, N.H., and Deshingkar, P. 1997. *Climate Change and Forests: Impact and Adaptation: A Regional Assessment for the Western Ghats, India*. Atmospheric Environment Issues in Developing Countries Series-No. 4. Stockholm Environment Institute. 93p.

Rizaldi Boer, M.Khaimuddin, and Ahmad Bey. 1999. *Vulnerability and Adaptation for Forestry Sector, Indonesia: 1st National Communication*.

Ron Benioff, Sandra Guill, and Jeffrey Lee. 1996. *Vulnerability and Adaptation Assessments, and International Hanbook*. Environmental Science and Technology Library, US Country Study Program.

World Bank/FAO/UNDP, 1996. *Cambodia Forest Policy Assessment*, 58pp.

World Bank, 1999. *Background Note. Cambodia, A vision for Forestry Sector Development*, 21 pp.

V. VULNERABILITY AND ADAPTATION FOR HUMAN HEALTH

V.1. Introduction

The relationship between climate and human health is not well understood and the methodology to assess the impact of climate change on human health is still at the early stages of development. However, there were some findings showing possible types of climate change impacts on human health. It should be noted that the impact could be both direct and indirect.

WHO, WMO, and UNEP (1996) reported that the direct impacts of climate change on human health include exposure to thermal extremes. Frequency and/or intensity of extreme weather events may increase and this could result in death, injuries, psychological disorders, and damage to public health infrastructure. Whereas the indirect impacts include the disturbances of ecological ecosystems that cause changes in geographical range and incidence of vector-borne diseases, infectious diseases, malnutrition and hunger which in turn disturb child growth and development. Furthermore, sea level rises may force population displacement and cause damage to infrastructure. This will lead to increased susceptibility to infectious diseases and psychological disorders.

Many infectious diseases such as malaria, dengue fever, diarrhea and other water and food borne diseases are found to be susceptible to the climate change. Martens *et al*. (1995b) estimated that by the year 2100, mosquito populations would increase two folds in tropical countries and more than 100 fold in temperate countries as a result of an increase in global mean temperature of several degrees. Temperatures of between 25 and 27^{o}C are very favorable for mosquitoes' development. A study in the U.S.A. has found that warmer winters would increase mosquitoes, cockroach and termite populations. Precipitation is another important factor that influences insect growth rate especially mosquitoes and black flies because many of these species breed in the residual water that remains after flooding in the rainy season. However, heavy rainfall may wash vector larvae away or kill them directly.

At the present time, it is estimated that 5% of the world population is infected by malaria, with approximately 350 million new cases occurring annually (WHO, 1995a). In Cambodia, Laos PDR, Myanmar, Thailand and Vietnam nearly 700,000 cases were recorded annually (WHO, 1993a). Therefore, study on the impact of climate change on this disease is very important. This study is aimed to assess vulnerability of human health, particularly malaria, to climate change.

V.2. Human Diseases in Cambodia

Based on health statistics reports, the main health problems in Cambodia are malaria, diarrhea, dysentery, ARI, dengue fever (DHF), meningitis, measles, AFP, tetanus, TB, road and mine accidents, and gyneco obst (Figure 5.1). Climate condition in tropical countries like Cambodia, is very favorable for insects including vectors transmitting disease, therefore, a significant quantity of infectious diseases, such as malaria are commonly found in the country. It was reported that more than 10% of all inpatients were infected with malaria (Table 5.1).

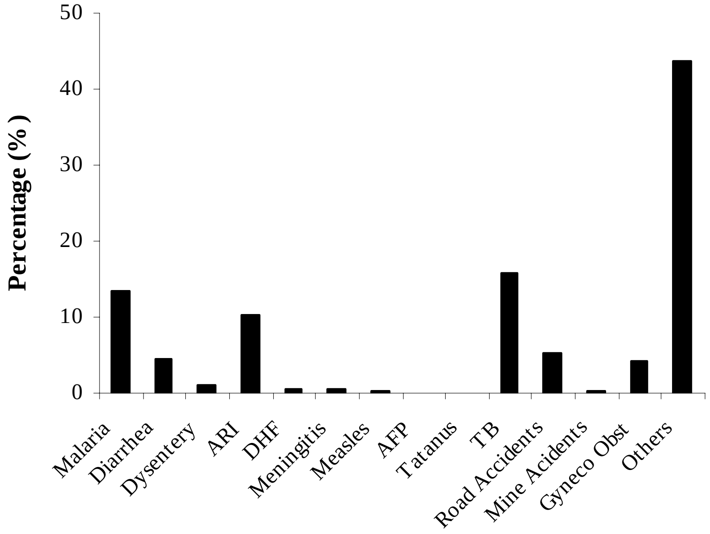


Figure 5.1: Percentage of People Infected by Diseases in 1999
(Note: Total cases was 195,790 people; Ministry of Health, 1999)

Table 5.1: Percentage Infectious Diseases for all Inpatients

Year	Malaria	Dengue	Diarrhea	Dysentery
1995	11.00	4.00	7.00	2.00
1996	13.00	1.00	6.00	2.00
1997	13.71	2.43	3.52	1.38
1998	13.00	3.03	3.98	1.32
1999	13.55	0.60	4.44	1.16

Sources: Ministry of Health (1995-1999).

In the case of malaria, according to National Malaria Control Center (1999) Cambodia can be divided into three main malaria regions. The first region is the northeastern and northwestern provinces and the rubber plantations, which cover about 4.5% of the total population. This region is relatively sensitive to malaria. The second region is the central part, which is considered as quite sensitive region to malaria (medium sensitive). The third region is the remaining which is considered as less or not sensitive region.

A regional study indicated that the death rate from malaria in Cambodia was higher than neighboring countries (about 800 deaths/year). Low standard of living and the limitations of education as well as other social issues such as personal hygiene and traditional beliefs may contribute to these conditions. For example in some provinces, the percentage of literate people is less than 30% and the percentage of unemployment is also high (see Appendix 5.8.1 for details). Consequently, the National Malaria Control Center has attempted to minimize the number of malaria cases by implementing various activities with cooperation and support from Ministry of Health, funding agencies, IOs and NGOs. The efforts include the distribution of bed nets impregnated with chemicals, medicine and insecticide repellant practices, health care staff training, education etc.

Realization of the program for distributing bed nets has increased quite significantly. In 1999, the realization achieved 90% of the plan. Access to remote areas proves to be problematic and heavy rain often exacerbates difficulties. NGOs and IOs such as World Health Organization (WHO), European Union (EU), Oxfam GB, Red Cross and the Cambodia Daily Mosquito Net Campaign play significant roles in supporting provincial health department with bed net and chemical distribution campaigns.

Traditional beliefs on malaria is an important factor that contributes to the high death rate from this disease. To address this, health education projects have been implemented with aims (i) to increase awareness of people to the causes of infectious diseases especially malaria, and (ii) to introduce simple ways to protect people from these diseases. Types of programs already implemented include poster distribution and campaigns through mass media.

Insufficient staff numbers as well as their limited technical expertise in using modern technology are also hampering government efforts to reduce the high death rate from malaria. In dealing with this, the National Malaria Control Center in cooperation with NOGs have conducted training programs for improving their knowledge on malaria treatment and introduced new technologies to health care staff and military in almost every province. Data from 1995 to1999 indicates that the number of provinces covered by the program increased as well as number of participants (Table 5.2), whereas, bed occupancy rate decreased from 51% in 1996 to 43% in 1999 (see Appendix 5.8.2 for details).

Table 5.2: Comparison of Training Program from 1995-99

Year	No. of Provinces	No. of Participants
1995	8	71
1996	11	113
1997	12	157
1998	18	192
1999	15	183

Source: National Malaria Control Center, 1999.

V.3. Malaria Incidence and Climate Variability

In order to evaluate the possible impact of climate change on malaria incidence, malaria data in each province from 1996 to 1999 were analyzed. The provinces were classified into three regions, namely low land, coastal and high land. Monthly malaria cases per 100,000 people in each region were plotted (Figure 5.2). It was clearly shown that the number of malaria cases in the high land provinces is consistently higher than in the lowland and coastal provinces. The number of malaria cases per 100,000 people in the high land provinces were generally more than 1,000 cases while the coastal provinces had less than 1,000 cases and in the low land provinces had less than 100 cases.

A study in Africa indicated that in low altitude zone, rainfall and temperature is the most significant climate factors for malaria incidence, while in high altitude area monthly malaria incidence was exponentially affected by changes in minimum temperature. It was concluded that areas near the current limits of malaria distribution would potentially be most vulnerable to climatic changes. A small increase in minimum temperature might facilitate this spread of malaria (Patc and Balbus, 1996). In Zimbabwe, malaria prevalence was inversely related to altitude. Malaria ranged from being hyperendemic at altitude below 600 m to being absent on the central highland above 1200 m.

By observing monthly variations of malaria cases, it was found that in some provinces, the malaria cases tended to increase at the beginning and at the end of the rainy season (Figure 5.2). A strange case was found in Modulkiri province where at the beginning of La-Nina year malaria cases increase very quickly and then dramatically decrease at the end of the rainy season. This peak seems to be abnormal and totally different from other provinces within the region. This phenomenon cannot be explained due to a lack of available data, and therefore further study is needed.

Variation of malaria cases between years was also not very different. This indicates that in Cambodia, the relationship between malaria cases and ENSO events was not very strong (1997/98 was known as El-Nino years while 1998/1999 was La-Nina years). However, in some provinces such as Kampot, number of cases increased significantly when the El-Nino started and then tended to decrease in the La-Nina period. The other findings suggest that the number of malaria cases in Kampot was significantly higher than other provinces in the same region. This might be due to the differences in socio-economic factors of the provinces (see Appendix 5.8.1). Similar condition was also observed in Siem Reap and Pursat. In El-Nino years, the number of malaria cases tended to increase and then decrease in La-Nina years (Figure 5.2). A summary of malaria cases per year in normal, El-Nino and La-Nina years in the four regions is presented in Appendix 5.8.3.

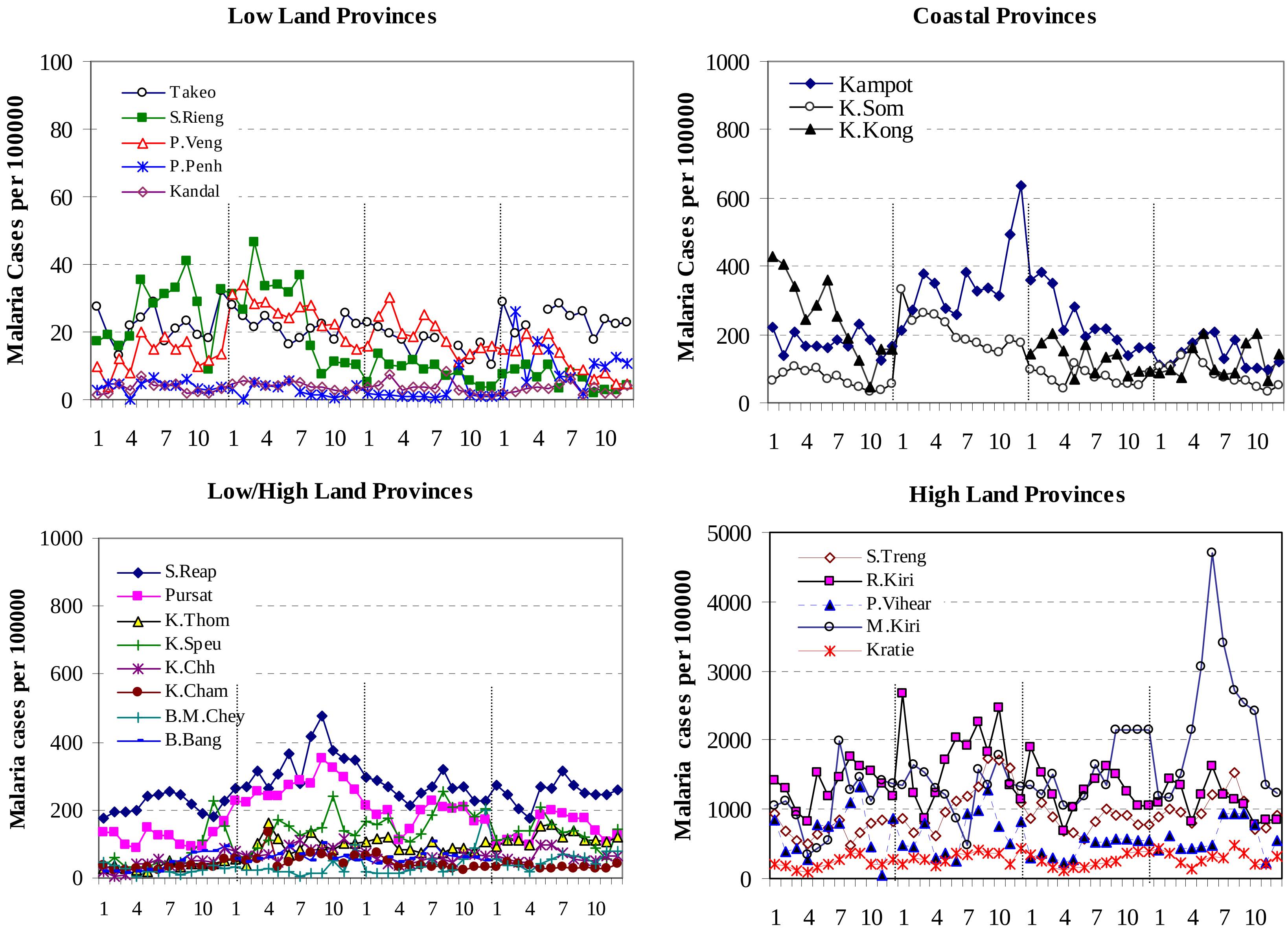


Figure 5.2: Monthly Malaria Cases in Provinces from 1996 to 1999 According to their Topographical Group

V.4. Impact of Climate Change on Malaria Incidence in Cambodia

V.4.1. Methodology

The impact of climate change on malaria incidence was evaluated using two GCM models, CCSR and CSIRO and two emission scenarios, SRESA2 and SRESB1 (see Chapter II for details). Based on the above preliminary findings, a model that explained variability of malaria cases between months, years and provinces was developed using regression techniques where wet season rainfall (WSR), dry season rainfall (DSR), annual mean temperature (AMT) and socio-economic condition of the province were used as independent variables. In this study, socio-economics of provinces was only represented by percent of literate (Appendix 5.8.2). Figure 5.3 illustrates the methodology used in this study.

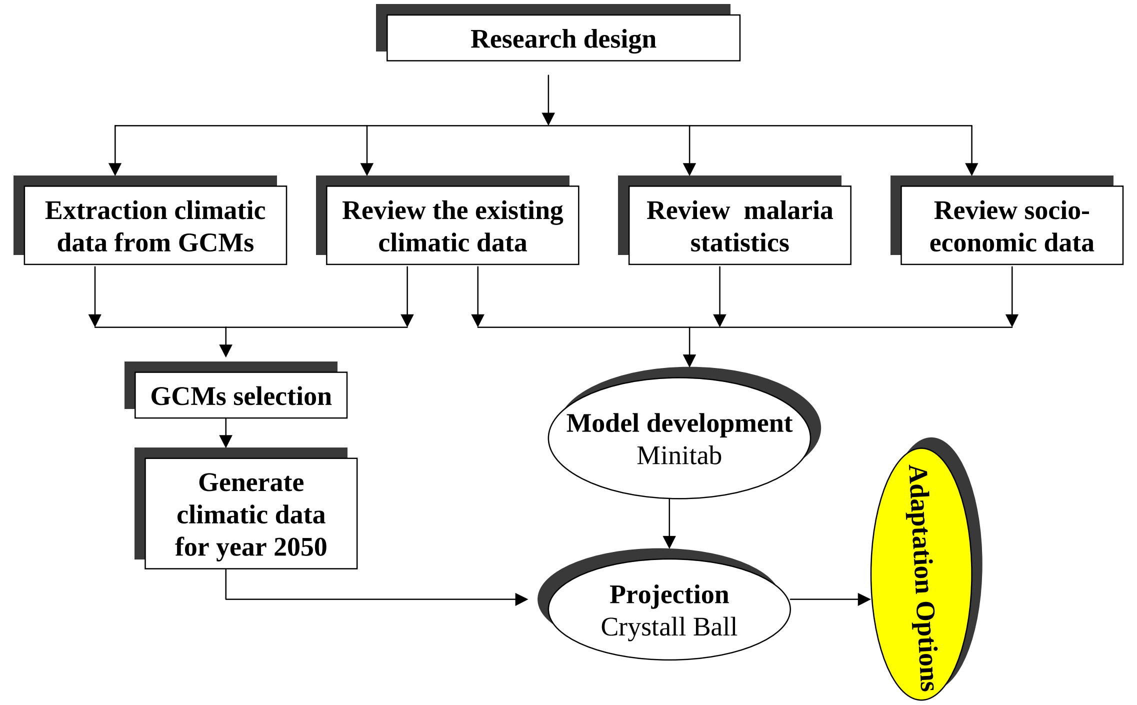


Figure 5.3: Schema of Research Design

Temperature data in Cambodia is available at only 7 stations (Kampong Som, Kampot, Pochentong, Battambang, Siem Reap, Kratie, and Stung Treng). Therefore, temperature data in other provinces were estimated using weighted average of altitude of the provinces. The equation used for estimating temperature data can be found in Chapter II. Variability of temperature between years in these provinces was assumed to be the same as that in Pochentong station. This station is considered to have reliable data since it is directly under inspection of Meteorological Department (Appendix 5.8.2)

Impact of climate change on malaria cases was evaluated using a stochastic spreadsheet. With this technique, variability in rainfall and mean annual temperature as well as model error were taken into account.

V.4.2. Results and Discussion

This study showed that most of the variability of malaria cases that occurred in the last four years (1996-1999) can be explained by about 72% by the variability of wet season rainfall (WSR; May to October), dry season rainfall (DSR; November to April), mean annual temperature (Tmean) and percent literate people in the province (PL). The equation is as follow:

$$Y = 24268 - 1.37\ DSR + 1.55\ WSR - 103\ Tmean - 342PL$$

The above equation indicates that the number of malaria cases is negatively correlated with dry season rainfall, means of annual temperature and percent literate, and positively correlated with wet season rainfall. PL was found to contribute to most of the variation in malaria cases in Cambodia (46%) and followed by WSR (29%), Tmean (19%) and DSR (6%).

Based on the above equation, projection of malaria cases in the future under SRESA2 and SRESB1 by using two GCM models (CCSR and CSIRO) was developed with the assumption that no change in literacy percentage from the current condition. It was found that in 2050 malaria cases in most parts of southeastern provinces would be the lowest and followed by the northwestern part of the country (Figure 5.4). But in fact, the highest malaria risk region is the northeastern part followed by the northwestern provinces. The projection for northwestern provinces was lower than it would be expected based on the actual malaria incidence. This is probably because the model can not capture the variability of malaria cases in these provinces. This problem may arise as a result of the use of unrepresentative data. Malaria cases from these provinces did not include remote areas (forested and mountainous). These areas have been observed as the most high-risk regions for malaria incidence (e.g. Pailin, Kravang district, etc.). This limitation may lead to high uncertainty in projection in particular for this region. For further study, it is recommended that the model needs to be updated using more extensive data records that cover most of the sensitive areas.

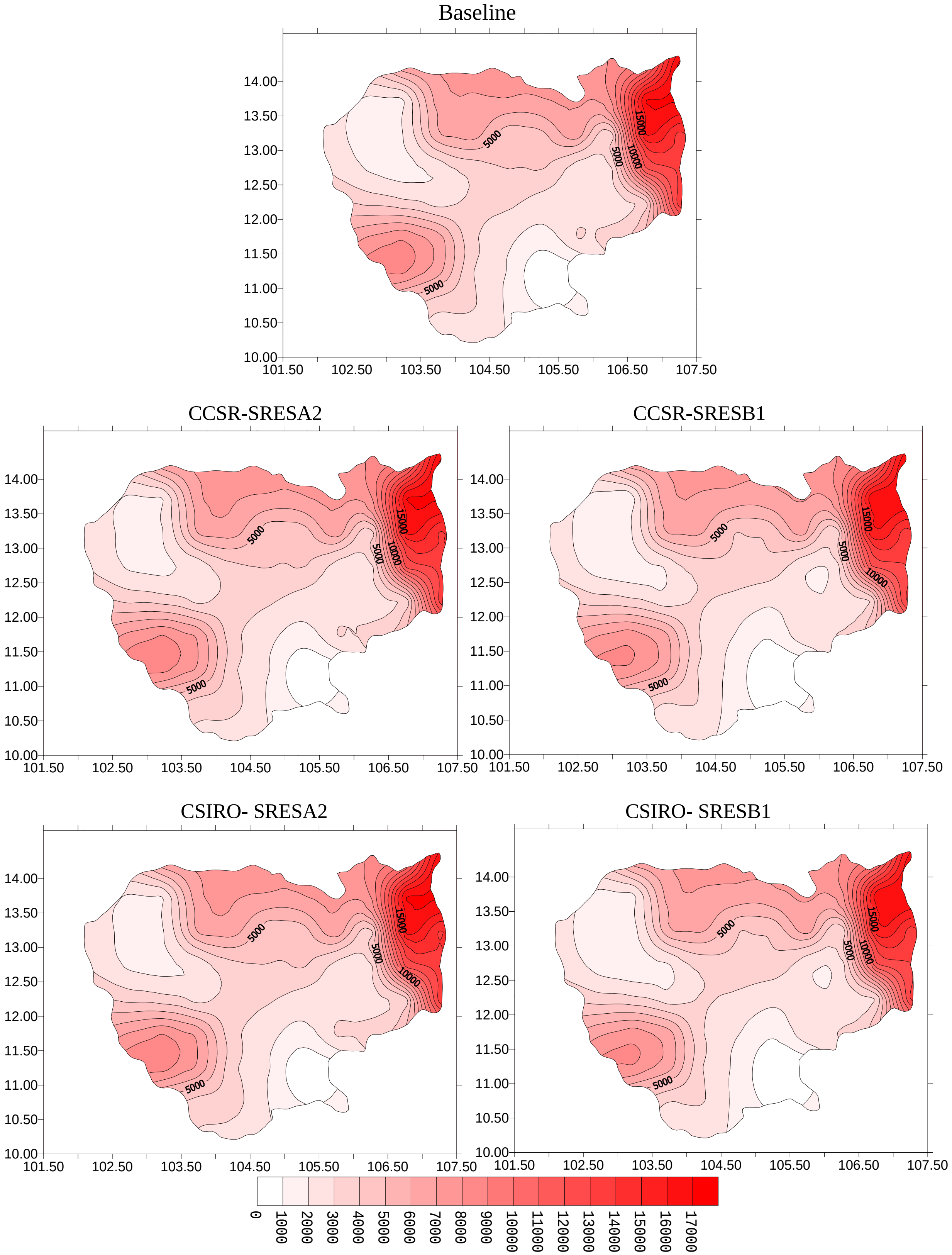


Figure 5.4: Spatial Variability of Malaria Cases in Cambodia under Current Condition and in 2050

Table 5.3 presents the percentage change of malaria cases in 2050. It was indicated that average number of malaria cases in most provinces would consistently decrease under changing climate using SRESB1 scenario under both GCM models (CSIRO and CCSR) in a range of –62 to –1%. Yet, the projections under SRESA2 scenario for the two GCMs result in increased malaria cases, which are represented by the percentage of change ranging from –1 to 16%.

Both GCM models provided similar results, but changing scenarios leads to different outcomes. Under SRESB1 scenario, Svay Rieng province would see a dramatic drop in the malaria cases in the year 2050 up to 50% and 62% by using CCSR and CSIRO model respectively. In contrast, under SRESA2 scenario, the cases tended to increased by 16 and 7% for CCSR and CSIRO respectively.

Table 5.3: Percent Change of Malaria Cases from Current Condition in 2050 by Provinces

Province	CCSR		CSIRO	
	SRESA2	SRESB1	SRESA2	SRESB1
Banteay Meanchey	8	-3	9	-1
Battambang	3	-10	5	-8
Kampong Cham	1	-10	-1	-13
Kampong Chhnang	8	-2	11	-1
Kampong Speu	4	-7	4	-6
Kampong Thom	2	-4	3	-4
Kampot	10	-1	8	-4
Kandal	4	-12	1	-13
Koh Kong	3	-3	3	-2
Kratie	7	-6	3	-8
Mondulkiri	1	-2	0	-2
Preah Vihear	1	-2	1	-2
Prey Veng	13	-9	12	-17
Pursat	2	-9	5	-7
Ratanakiri	0	-2	0	-2
Siem Reap	2	-1	2	-1
Sihanoukville	7	-5	5	-5
Stung Treng	1	-1	1	-2
Svay Rieng	16	-50	7	-62
Takeo	8	-13	4	-15

From the regression equation, it can be seen that the percent literate people explain most of variation in malaria cases in Cambodia. Figure 5.5 illustrates how the number of malaria cases will change if the percent literate people is increased in two selected provinces (the most vulnerable provinces).

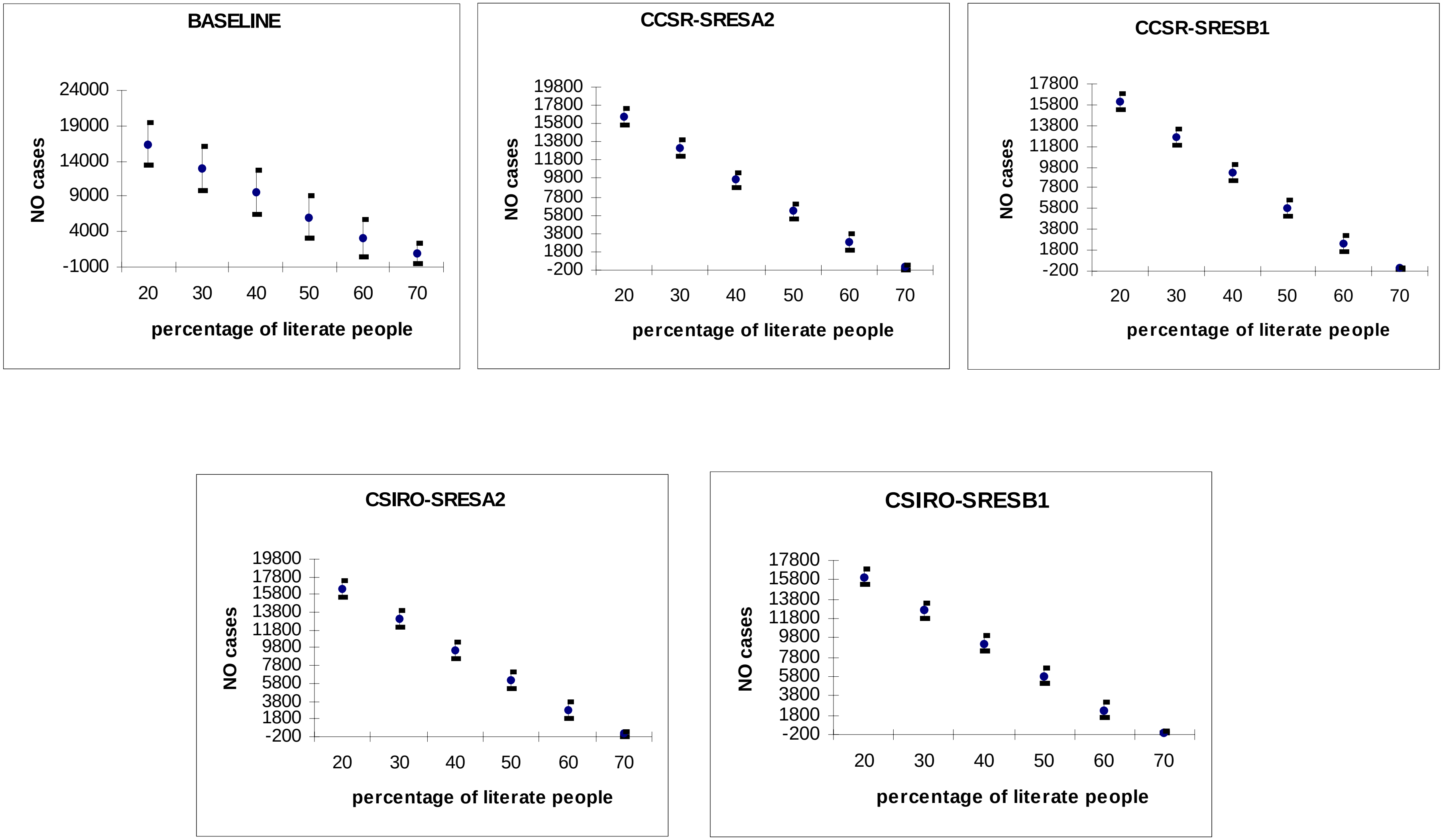


Figure 5.5: Changing of Malaria Cases Vs Changing of PL in Kampot Coastal Province

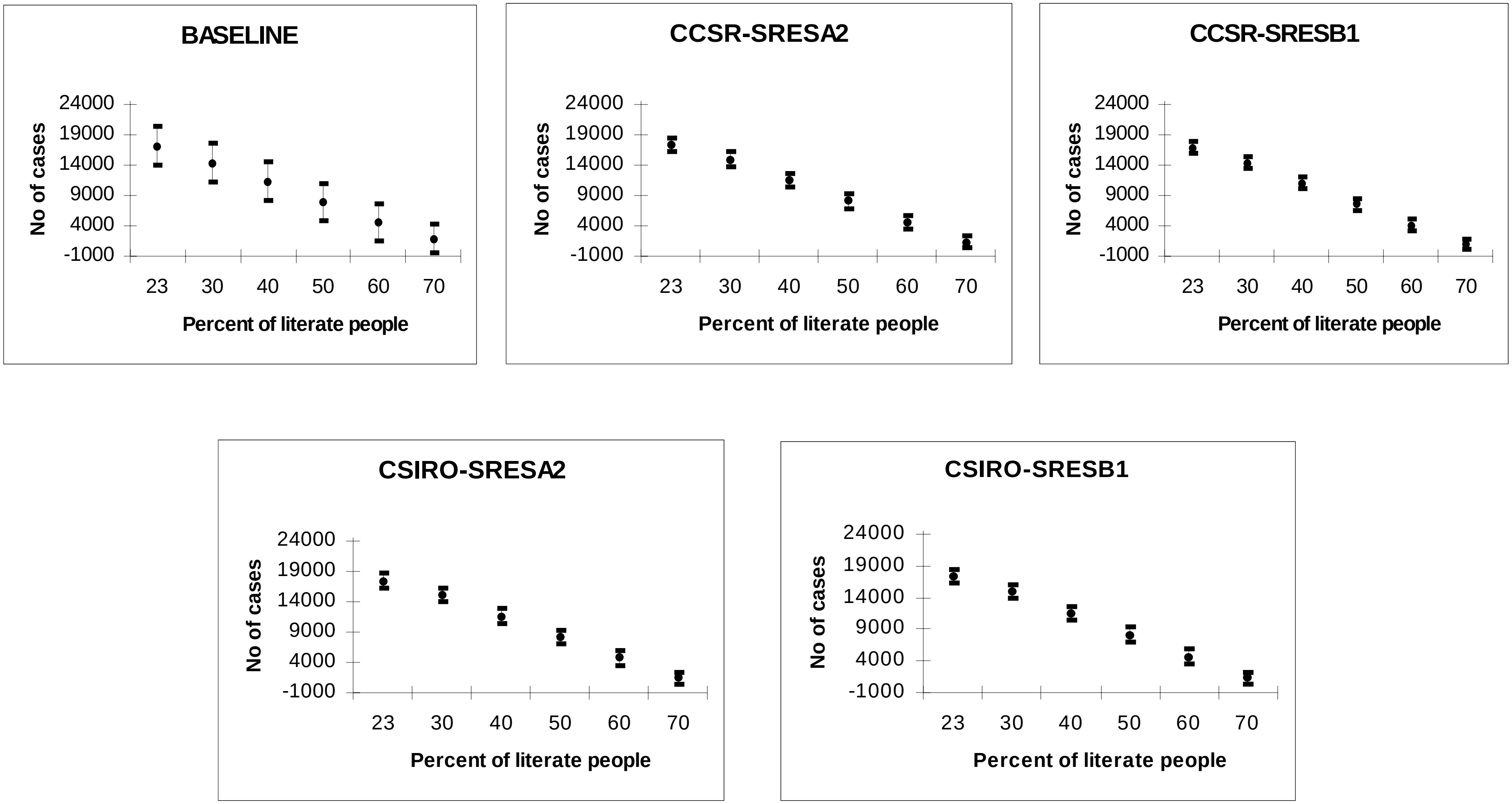


Figure 5.5 (cont.): Changing of Malaria Cases Vs Changing of PL in Ratanakiri High Land Province

V.5. Adaptation Options

Control measures being introduced focus on the reduction of malaria mortality and morbidity through early diagnosis and treatment of the disease. Vector controls are being introduced based on the utilization of pyrethroid treated mosquito nets to communities living in high risk situations. Funds for the provision of mosquito nets and insecticide are still required, and the program's management and supervisory practices need to be strengthened.

The programs for health education should focus on the most critical causes of disease: watercourses and containers where mosquitoes' breed and personal habits, which are conducive to the attack of parasitic and infectious organisms. Low cost preventative methods such as improvement of personal hygiene and surrounding environment by destroying the insect breeding sites and use of bed nets should also be emphasized. In this respect, the education materials should be simple enough as the level of education in rural communities is often low. In conjunction with this, the improvement of general education is another effective strategy to diminish malaria incidents and this is clearly shown by the above equation (Sector 5.4).

V.6. Conclusion and Recommendations

Based on monthly historical data from 1996-1999, variability of malaria cases in Cambodia can be explained mostly by wet season rainfall, dry season rainfall, mean annual temperature and percent literate people. Percent literate contributed to about 46% of total variation of malaria cases, while wet season rainfall 29%, mean annual temperature 19% and dry season rainfall 6%. Hence the promotion of education scheme will positively impact the malaria incidence. Other factors for welfare such as safe water supply, good sanitary facilities and hygiene education should also strongly influence the cases.

Under changing climate, it was found that the average number of malaria cases in most of provinces in Cambodia would consistently decrease in a range of –0.3 to –100%. In a few provinces, the impact of climate change on malaria incidence may be positive or negative depending on emission scenarios and the GCM model used. The number of malaria cases may increase in Banteay Meanchey either under CCSR or under CSIRO models for both emission scenarios.

In further studies, it is recommended that models used to estimate malaria cases need to be improved using data from a longer time period and covering most of sensitive areas. Continuing observation and good database management would be priority activity for facilitating the studies.

V.7. REFERENCES

Department of Forestry, 1999. *Assessment of Forest Covers in Cambodia*. Phnom Penh, Cambodia.

Martens WJM et al., 1995b. *Potential Impacts of Global Climate Change on Malaria Cases.* Environmental Health Perspectives.

Ministry of Health, 1995. *National Health Statistics Reports*. Phnom Penh, Cambodia.

Ministry of Health, 1996. *National Health Statistics Reports*. Phnom Penh, Cambodia.

Ministry of Health, 1997. *National Health Statistics Reports*. Phnom Penh, Cambodia.

Ministry of Health, 1998. *National Health Statistics Reports*. Phnom Penh, Cambodia.

Ministry of Health, 1999. *National Health Statistics Reports*. Phnom Penh, Cambodia.

Ministry of Planning. *Population Census 1998*. Phnom Penh, Cambodia.

National Malaria Control Center, 1999. *Report on the Actions Undertaken by National Malaria Control Center in 1999*. Phnom Penh, Cambodia.

Patz, J.A., and Balbus, J.M., 1996. *Methods for Assessing Public Health Vulnerability to Global Climate Change*. Climate Research 6, 113-125.

WHO, 1995a. *The World Health Report 1995: Bridging the Gaps*. Geneva.

WHO, 1993a. *A global Strategy for Malaria Control*. Geneva.

WHO, WMO, and UNEP, 1996. *Climate Change and Human Health*. UK.

V. 8. APPENDIX

Appendix 5.8.1: Percentage of Socio-economic Factors of all Provinces

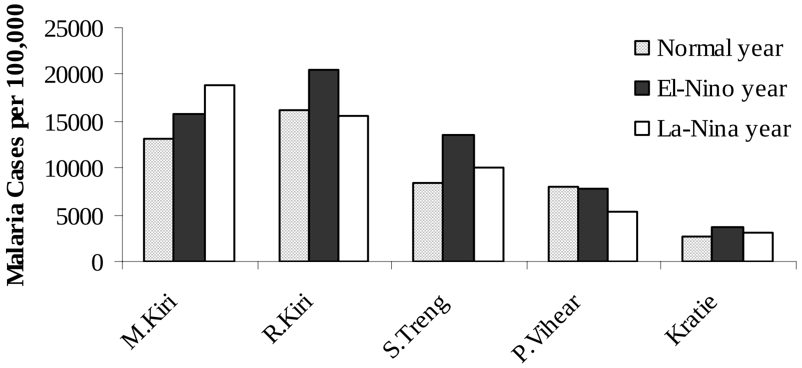
Province	Literate People	Unemployment Rate	Piped Water & Well	Toilet Facility
Battambang	65.0	8.0	11.9	19.9
Banteay Meanchey	63.8	8.0	12.5	10.4
Kampong Cham	61.0	4.3	13.4	9.7
Kampong Chhnang	58.9	3.1	18.2	6.0
Koh Kong	55.0	9.3	3.3	14.7
Sihanoukville	64.1	8.3	11.3	25.2
Kampong Speu	59.8	2.8	19.0	3.9
Kampong Thom	56.4	8.2	3.1	13.1
Kampot	59.3	3.7	7.2	8.0
Kandal	68.8	4.9	17.0	12.3
Kratie	61.5	6.9	20.3	13.4
Mondulkiri	32.8	7.3	1.6	11.4
Phnom Penh	82.7	12.6	50.6	74.9
Prey Veng	64.4	3.0	53.8	4.3
PreahVihear	48.7	2.6	17.1	4.9
Pursat	62.2	3.5	6.4	8.5
Ratanakiri	23.5	3.0	3.6	9.2
Siem Reap	48.2	4.6	12.8	6.6
Svay Rieng	67.1	2.1	47.9	8.2
Stung Treng	48.4	3.3	15.8	13.8
Takeo	60.5	3.5	10.9	4.3

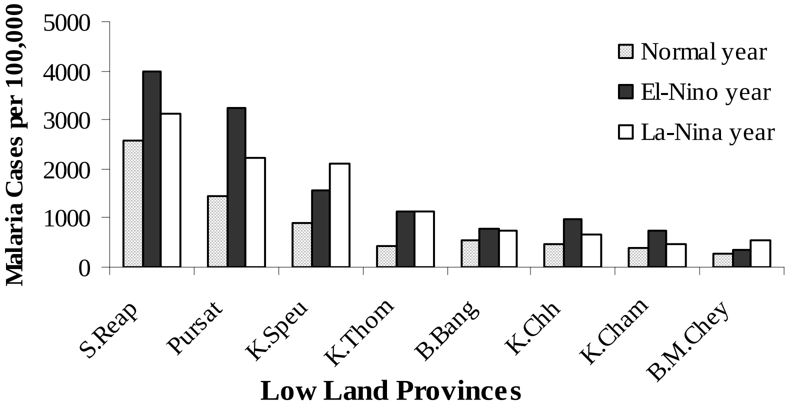
Source: Population Census 1998.

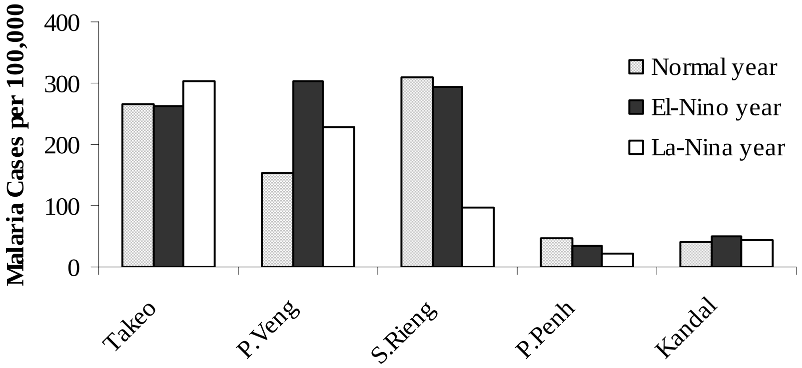
Appendix 5.8.2: Adjusted Mean Temperature for all Provinces

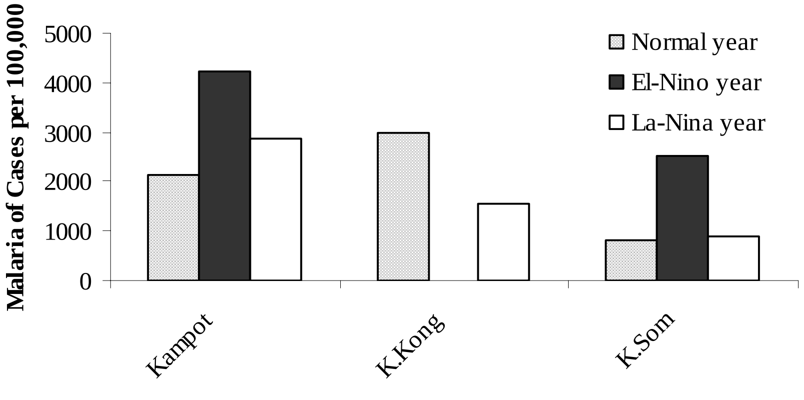
Province	Altitude (m)	1996	1997	1998	1999
Takeo	8	26.60	26.14	26.09	26.14
Prey Veng	10	26.59	26.13	26.08	26.13
Svay Rieng	6	26.61	26.15	26.10	26.15
Phnom Penh	6	26.61	26.15	26.10	26.15
Kandal	10	26.59	26.13	26.08	26.13
Siem Reap	218	25.37	24.91	24.86	24.91
Pursat	930	21.19	20.73	20.68	20.74
Kompong Speu	125	25.92	25.45	25.40	25.46
Kompong Thom	28	26.48	26.02	25.97	26.03
Battambang	58	26.31	25.85	25.80	25.85
Kompong Chhnang	253	25.16	24.70	24.65	24.71
Kompong Cham	84	26.16	25.69	25.64	25.70
Banteay Meanchey	70	26.24	25.77	25.73	25.78
Mondulkiri	633	22.94	22.47	22.42	22.48
Rattanakiri	825	21.81	21.35	21.30	21.35
Stung Treng	200	25.48	25.01	24.96	25.02
Preah Vihear	320	24.77	24.31	24.26	24.31
Kratie	74	26.21	25.75	25.70	25.76
Kampot	20	26.53	26.07	26.02	26.07
Koh Kong	756	22.21	21.75	21.70	21.76
Sihanoukville	107	26.02	25.56	25.51	25.56

Appendix 5.8.3: Number of Malaria Cases in Each Province by Regions in Normal, El-Nino and La-Nina Years


High Land Provinces


Low/high Land Provinces


Low Land Provinces


Coastal Provinces

VI. VULNERABILITY AND ADAPTATION FOR COASTAL ZONE

VI.1. Introduction

The coastline of Cambodia extends along the northeastern shore of the shallow Gulf of Thailand between the Thai and Vietnamese borders for approximately 435 km. The Cambodian coastal zone consists of estuaries, bays, and some 64 islands of various dimensions, including three off-shore islands named Koh Tang, Koh Pring, and Koh Polowaii (ADB, 2000). Three provinces and one autonomous city, namely Kampong Som, Kampot, Koh Kong, and Kep city, lie along the coast (Appendix 6.7.1) with a total population of 675,000 inhabitants.

The coastal zone plays an increasing role in Cambodia's development and continues to provide important environmental services. Increasing human activities Cambodia's coastal zone include recreation, industry, agriculture, fishery and transport. These activities may have direct or indirect effects on changing the coast. Recreation and tourism is an important sector among others. The beaches and islands attract an increasing number of tourists. A survey has indicated that the highest tourism activity takes place in Kampot and Kampong Som provinces. The Provincial Offices of Planning reported that about 111,000 tourists visited the coastal provinces in 1995. It was reported that about 10% of the profit from private tourist industries went to the provincial government through taxes. A case study indicated that the number of tourists visited Kep City increased from 38,735 to 67,990 in 1997 and 1998 respectively.

Agriculture activities in the coastal zone are also quite significant. About 5% of the population in Koh Kong and 45% in Kampong Som are engaged in agricultural activities (MoE and UNDP, 1994). The activities are concentrated mainly in low-lying coastal areas because of the fertility of the land (Kampot Department of Agriculture, 1995). Salt farming is also a major economic activity in Kampot province and Kep City (Danida and MoE, 2000). It was reported that the production of salt sharply increased from 76,000 tonnes to 152,000 tonnes in 1996 and 1998 respectively.

As the coastal zone in very important for the Cambodian economy, a study to evaluate the vulnerability of the area to climate change, in particular, to sea level rise is very important. The increase of sea level will have adverse impacts on social and economic activities of the people and the environment, in particular in the low-lying areas.

The major objectives of this study are:

- To identify the coastal problems and related constrains and coastal management options under extreme climate conditions;
- To assess potential impacts of a 1 m rise in sea level on the Cambodia's coastal zone; and
- To develop response strategies to the possible impact of climate change on the Cambodia's coastal zone.

VI.2. State of the Coastal Zone

VI.2.1. Climate and Soils

Annually, the coastal area receives about 2,000 to 4,000 mm of rainfall (ADB, 1996). Mean daily temperature ranges from 26.5 to 28.5^{o}C with minimum temperatures of between 21 and 23^{o}C and maximum temperatures of between 31.5 and 34.6^{o}C. Relative humidity ranges from 79 to 82%.

Soil types vary between locations and most are shallow soils (thickness of between 10 and 30 cm; MoF, 1996).

VI.2.2. Land Use

Most of the coastal zone is covered by coastal forest and mangrove (Table 6.1). The use of land for agriculture activities in Kampong Som, Kampot and Koh Kong is about 14%, 34% and 4% of the total areas respectively. This indicates that the contribution of the agriculture sector to the economy is more significant in Kampot than in the other two provinces.

Table 6.1: Land Use in the Coastal Zone of Cambodia

Land Use Category	Kampong Som	Kampot	Koh Kong	Kep
Coastal Forest	95,800	266,900	1,126,300	n/a
Mangrove & swamps	13,500	7,900	63,700	n/a
Rice	12,800	152,500	17,300	2,500
Upland crops & others	7,200	20,000	35,600	35
Others	13,300	54,700	53,400	n/a
Total	142,600	502,000	1,296,300	n/a

Source: Landsat satellite imagery from the Mekong Secretariat (1994).

VI.2.3. Natural Resources

Mangrove Forests. The mangrove forests in Koh Kong have been considered as ecologically and economically significant to Cambodia as well as to all countries situated around the Gulf of Thailand (Bann, 1996). It is therefore necessary that those mangrove forests should be protected and reserved as they are of vital importance not only for Cambodia but also for other countries located in Southeast Asia Continent. There are about 17 families and 34 species of which *Rhizophora mucronata* and *Rhizophora conjugata* found in the area (ADB, 1996).

Coral Reefs. Coral reefs are located in almost all areas around both inshore and offshore islands and some are found in bad condition due to sedimentation. Well-developed coral reefs are found around Koh Rong, Koh Rong Sanlem, Koh Russey, Koh Takiev, Koh Thmey and Koh Ses islands of Kampong Som province; Koh Tunsay island of Kep city; and Koh Tang, Koh Pring and Koh Chlarm offshore islands (ADB, 1996). It has been found that coral reefs are being harmed by human activities such as collection for selling, boat anchoring, push net fishing and trawling.

Seagrasses. Seagrass beds have been found in sheltered estuaries which are located between the Vietnamese island of Phu Quoc and the Cambodian Bay in Kampot province. There are many species of seagrasses, including *Enhalus acoroides*, *Cymodoces seradata*, *Syringodium isoetifolium*, and *Haloduel pinipolio* (Cambodia's Ministry of Environment, 1994). Seagrass beds usually play a vital function in marine ecosystems by: (i) providing a good habitat for aquatic life, including fish, invertebrates, mammals, turtles, and dugongs; (ii) stabilizing coasts, (iii) exporting nutrients to surrounding ecosystems; and (iv) interacting with coral reefs and mangroves.

Marine Fisheries. Cambodia has approximately 435 species of marine fish living within the coastal zone. The recent annual catch of fish has reached approximately 30,000 tonnes, which is much higher than that of previous years (Department of Fishery, 1996). The total catch fluctuated from year to year (Table 6.2).

Table 6.2: Total Annual Marine Fishery Harvests in Cambodia, 1980-1995

Year	Total Catch (tonne)	Year	Total Catch (tonne)
1980	1,200	1988	21,000
1981	814	1989	26,050
1982	3,015	1990	39,900
1983	9,444	1991	36,400
1984	7,721	1992	33,700
1985	11,178	1993	31,100
1986	7,247	1994	30,000
1987	17,417	1995	30,500

Source: Department of Fisheries, 1996.

VI.2.4. Protected Areas

In the coastal zone, there are four national parks, three wildlife sanctuaries and a multiple use area (Table 6.3). These protected areas play a crucial role in maintaining ecological functions and services in the coastal zone. Currently natural resources within these protected areas are under increasing pressure from agricultural and industrial development; human settlement; illegal logging, fishing and hunting; land encroachment; etc. The Ministry of Environment, which is responsible for managing all the country's protected areas, have made strong efforts to protect these coastal protected areas with support from various donors such as DANIDA, IDRC, ADB, UNDP, and some international NGOs.

Table 6.3: List of Protected Areas in the Coastal Zone

Name	Area (ha)	Province
1. National Parks		
Kirirom	35,000	Koh Kong/Kampong Speu
Phnom Bokor	140,000	Kampot
Kep	5,000	Kampot
Ream	15,000	Kampong Som
2. Wildlife Sanctuaries		
Phnom Aural	253,750	Koh Kong/Pursat/Kampong Chhnang
Peam Krasob	23,750	Koh Kong
Phnom Samkos	333,750	Koh Kong
3. Multiple-Use Areas		
Dang Peng	27,700	Koh Kong

Source: Ministry of Environment, 1994.

VI.2.5. Water Resource and Hydrology

The main source of surface water in the coastal zone is rivers, streams, and lakes. The coastal rivers and streams are normally short and start from hills of approximately 500 to 600 m altitude (Ministry of Environment, 1994). The rivers and streams are full of water during the rainy season. They are also influenced by the sea. The downstream parts of the low-lying rivers and streams are filled by the seawater during the dry season.

Koh Kong. In Koh Kong province, there are four main rivers, namely Stung Metoek, Stung Russei Chrum, Stung Sala Munthun, and Stung Tatey. At present, the resources of these rivers have not been used very much although some hydopower development plans were developed many years ago during the 70's.

Stung Metoek takes its source from Phnom Thom. The river has a catchment area of about 1,135 km^2 up to the point where it enters the Prek Koh Pao Estuary. The Stung Metoek Basin is mountainous and sparsely populated. The rainfall over the Stung Metoek Basin is about 3,305 mm/year and the average flow of the river is approximately 86 m^3 /s.

Stung Russei Chrum takes its source from the highlands in Pursat province. The river flows via the Prek Koh Pao Estuary into the Gulf of Thailand near Koh Kong City. The river has a catchment area of about 2,726 km^2 up to the point where it enters the Prek Koh Pao Estuary. Similar to the Stung Metoek Basin, the Stung Russei Chrum Basin is mountainous and virtually unpopulated. The average rainfall over the Stung Russei Chrum Basin is 2,665 mm/year and average flow of the river is 152 m^3 /s. Among the Cambodian rivers that discharge into the South China Sea, Stung Russei Chrum is the greatest with 5 billion m^3 per year.

Stung Sala Munthun collects its headwaters in the Cardamom Mountains in Thmar Baing District with a catchment area of 1,568 km^2 up to the point where it enters the Prek Klang Yai Estuary. The river flows via the Prek Klang Yai Estuary into the Gulf of Thailand opposite Koh Kong Island. Stung Sala Munthun Basin is also mountainous and virtually unpopulated. The rainfall over the Stung Sala Munthun Basin is about 2,783 mm/year on average. The average flow of the Stung Sala Munthun is about 93 m^3/s.

A major tributary of Stung Sala Munthun is Stung Kep. Stung Kep with one major tributary, Stung Tatey, so named after the village located near its source, joins Stung Sala Munthun north of Koh Kong Town. Stung Chhay Areng has the following tributaries: Prek Yuon, Prek Smohn and Prek Tachan. The river flows via the Prek Klang Yai Estuary into the Gulf of Thailand opposite Koh Kong Island. Before reaching the sea, it joins Stung Tatey. The river has a catchment area of about 2,107 km^2. The upper and middle Stung Chhay Areng Basins are generally mountainous. However, there is a rather large plain in the upper Stung Chhay Areng Basin at 200m above sea level. The lower Stung Chhay Areng Basin is sparsely populated. The rainfall over this river is about 2,873 mm/year on average. The average flow of Stung Chhay Areng river is 131 m^3/s.

Kampong Som. In this province there is a natural waterway called Prek Piphot, formed up on the top of hills and consisting of cascades and waterfalls. It empties into Kampong Som Bay. Prek Kampong Som flows into Kampong Som Bay near Sre Ambel. Its tributaries are Stung Kombot and Stung Samrong. It takes its source from Veal Sbov Touch Village, Thmar Bang District, Koh Kong Province and its flows are considered to be one of the greatest in the coastal area with slightly less than 5 billion m^3 per year.

Kampot. Prek Kampong Bay has two large tributaries, the Prek Toeuk Chhou and Stung Koh Sla rivers. The width of the river is 20m in the dry season and 80 m in the wet season. In the rainy season, the level of water in the Stung Koh Sla is high. Every year water from the Stung Koh Sla floods Kampot and Kampong Bay districts for at least five to seven days, destroying crops, rice fields and people’s property.

Between 1975 and 1978, a 13 km dam, called the Koh Sla Dam, was established across the Stung Koh Sla River. The dam has two water gates. Two main canals and a number of secondary canals connect the dam to surrounding rice fields. The dam and the water gates have been damaged to some extent by heavy floods. Another 3 km dam was built during the same period at Stung Keo which has two water gates, three main canals and several secondary canals.

Both dams and the gates are not being utilized. Both dams on the Stung Koh Sla River are very important for rice production in Kampong Bay, Kampot, Bantey Meas, Kampong Trach and Dang Tung districts, irrigating 20,000 ha of land in the rainy season and up to 10,000 ha of land in the dry season. Stung Daunnphe and Stung Touk Meas are two major rivers in Kampot that are located outside the coastal watershed. Stung Daunphe, located in Chumkiri district, is a tributary of Stung Anlong Damrei. The Daunphe River traverses Santepheap, Okron and Trapaeng Andoek rivers and meanders across Takeo province outside the coastal provinces.

Between 1975 and 78, the Anlong Damrei and Stung Daunphe Dams were established across Stung Daunphe. The 100m long Anlong Damrei Dam, 13 m high and 20 to 50 m wide, has two water gates. The 2.7 km Stung Daunphe Dam was also built from 1975-78. It has four gates and irrigates 5,000 ha of land in the rainy season and up to 1,500 ha in the dry season. Four main canals, ranging from 5 to 20 km were constructed to drain water to the Chhouk District. Stung Touk Meas has a large number of tributaries, meandering across Dang Tung and Banteay Meas Districts. It traverses Tuon Han before flowing to Vietnam. Stung Touk Meas has been used for the operation of a phosphate factory, for transportation and irrigation.

Apart from the above-mentioned rivers, there are several small streams which carry organic and other materials into the sea during the rainy season. The coast has large quantities of seasonal surface water. However, water resources have not yet been developed for agriculture, industrial or household use and thus many areas are greatly lacking sufficient quantities of water in the dry season. The lack of water for irrigation purposes and domestic use is a serious problem in many areas. In the near future, this problem will be more serious as there is a potential increase in population and agricultural and industrial activities.

VI.2.6. Population

Cambodia's coastal zone population growth rate has been increasing steadily since 1981. Statistics by Ministry of Planning has shown that Cambodia's coastal zone population increased from 673,000 in 1994 to 845,000 in 1998 (26%) implying an annual average growth rate of 5.7%. By year 2006, the population annual growth rate in the coastal areas is expected to decrease to about 2.91% (National Institute of Statistics (2000).

VI.3. Assessment of Vulnerability of Coastal Zone to Climate Change

VI.3.1. Methodology

The coastal zone being evaluated in this case study is only part of Koh Kong province, the area surrounding the provincial center of about 68.5 thousand hectares (Table 6.4). This area has been selected for two reasons. Firstly, the preliminary study suggested that this area is the most vulnerable to sea level rise as it is located in a low-lying area. Secondly, this area has high population density, valuable environmental resources and is facing dramatic economic and environmental changes.

The assessment of the area that will be drawn by sea level rise was carried out using Geographical Information System (GIS) technique. Some maps were developed for this analysis, namely coastal watershed map, land use map and topographic map. One-meter contour lines were developed based on a 20-meter contour map using linear interpolation technique.

Table 6.4: Land use in the Case Study Area

No.	Description	Area (ha)
1	City/Town	497.5
2	Village	295.7
3	Swimming Beach	12.5
4	Marsh	200.3
5	Forest	691.8
6	Secondary Forest	1,063.2
7	Shrub	328.8
8	Mangrove	55,339.8
9	Grassland	1,981.9
10	Rice Paddy	178.1
11	Crops	107.2
12	Shrimp Farm	452.6
13	Others	7,442.0
14	Total	68,591.3

VI.3.2. Impact of Global Warming

The Earth’s climate has warmed about 0.5 ^{0}C over the last century, and is expected to warm another 1.0-3.5 ^{0}C over the next century under “business as usual” scenarios (IPCC, 1995). Thermal expansion of ocean waters and melting of land-ice due to higher ambient temperatures would lead to a rise in the average level of the sea by about 50 cm by the end of the next century (Warrick et al., 1996; see Table 2.4). This rise would have a substantial impact on human society and environment. From a societal perspective, the six most important biogeophysical (or natural system) that will be affected by sea level rise are (Klein and Nicholls, 1999) increasing flood frequency probabilities, erosion, rising water tables, saltwater intrusion, and biological disturbance. While, the potential socio-economic impacts of sea-level rise can be categorized as follows:

- Direct loss of economic, ecological, cultural and subsistence values through loss of land, infrastructure and coastal habitats;
- Increased flood risk for people, land and infrastructure; and
- Other impacts related to changes in water management, salinity and biological activity.

VI.3.3. Impact of Sea Level Rise in Koh Kong Province

At present, many coastal areas such as Koh Kong province have experienced increasing pressures from human activities such as mangrove clearance, overfishing, and pollution. Inevitably, the province will be under pressure resulting from climate change in the form of sea level rise. Rising seas will increase the risk of flooding of low-lying areas, intensification of coastal erosion, and increased saltwater intrusion. In this study, the effect of an increase in sea level of less than one meter on land use pattern could not be detected due to the low resolution of the elevation map used. However, if the sea level is increased by one meter, many coastal areas will be inundated and Koh Kong provincial center will be affected severely (Appendix 6.7.2). It should be noted that, even though the increase in sea level rise less than one meter would only inundate very small areas, the level of risk of these coastal areas to flood may increase, in particular during the rainy season, due to potential changes in hydrological patterns of the coastal rivers.

In chapter II, it was shown that under rapid increase of CO_2 in the atmosphere (SRESA2 scenario), CCSR and CSIRO models suggested that rainfall in 2100 in the province would increase between 5 to 15%, while under the slow increase (SRESB1) the rainfall would change between –5 to 5%. The changes in rainfall will affect the volume of river flows (Table 6.5). The study suggested that the change in the average daily flow of the coastal rivers depends on emission scenarios and GCM models used. The changes will range between –2 and 4 m^3/s for Stung Metoek, between –4 and 9 m^3/s for Stung Russei Chrum, between –2 and 5 m^3/s for Stung Sala Munthun and between –2 and 10 m^3/s for Stung Chhay Areng. This study assumed that the change in average daily rainfall flow is linearly related to the change in annual rainfall. For future study, when data are readily available, factors that affect the form of the relationship should be accommodated properly using mechanistic models (hydrology balance models).

Table 6.5: Rainfall and Average Daily River Flow in Koh Kong Province under Current and Changing Climate

Description	**Rivers**			
	Stung Metoek	**StungRussei Chrum**	**Stung Sala Munthun**	**Stung Chhay Areng**
Baseline				
Catchment Area (km^2)	1,135	2,726	1,568	2,107
Rainfall (mm/year)	3,305	2,665	2,783	2,873
Average Daily Flow (m^3/s)	86.0	152.0	93.0	131.0
Year 2100	**Rainfall increase from baseline (%)**			
SRESA2-CSIRO	10	12	10	15
SRESA2-CCSR	2	3	2	2
SRESB1-CSIRO	1	-0.4	1	5
SRESB1-CCSR	-5	-5	-4	-3
	Average Daily Flow, m^3/s			
SRESA2-CSIRO	90.0	161.0	98.0	141.0
SRESA2-CCSR	86.9	154.3	93.9	132.3
SRESB1-CSIRO	86.5	151.7	93.5	134.3
SRESB1-CCSR	83.9	148.1	91.1	129.0

Further analysis showed that by increasing the sea level by about one meter, the total area that will be under sea water permanently would be about 44 km^2 (0.4% of Koh Kong Province). Mangrove is obviously the ecosystem that would be mostly affected by the sea level rise (Table 6.6 and Figure 6.1). Of the affected area of approximately 44 km^2, about 70% is mangrove forest. Other land use types that would be flooded quite severely due to sea level rise are shrimp farm (7.7%), grassland (6.8%), city/town (6.3%), and forest (4.1%). Mangrove forests can not adapt easily to rapid sea level rise because it endangers their way of interacting with the surrounding environment of trapping sediments with their roots. If the sediment becomes washed away, then the swamp can not be formed. Many of the marine animals which are of economic importance to man feed directly on detritus. Without mangrove and other coastal fringe ecosystems, both the habitat and food supply for these animals will be lost and hence populations would decline. As far as sea level rise is concerned, the impacts will not stop at the immediate coast. It may go further. Saltwater will penetrate upstream and inland. Agriculture will be affected by the seal level rise as the water supply is contaminated. This may lead to an adverse impact on the economy of the country.

Table 6.6: Area of Land to Be Lost in Case of Sea Level Rise by 1 m

No.	Description	Flooded Area (m^2)	Percentage (%)
1	City/Town	2,791,056	6.28
2	Village	778,603	1.75
3	Swimming Beach	104,233	0.23
4	Marsh	325,277	0.73
5	Forest	1,818,246	4.09
6	Secondary Forest	34,818	0.08
7	Shrub	127,170	0.29
8	Mangrove	31,143,672	70.08
9	Grassland	3,012,436	6.78
10	Rice Paddy	295,850	0.67
11	Crops	98,449	0.22
12	Shrimp Farm	3,452,438	7.77
13	Others	459,735	1.03
14	Total	44,441,984	100

Other serious damage due to sea level rise is the loss of the city. At present, Koh Kong’s population is estimated to be about 140,000 people and there are about 2,822 houses located in the town. With the increase in sea level, at least 56% of the city area would be inundated (Figure 6.1). It will therefore threaten about 1,580 houses in the town. Additionally, houses which are in the vicinity of inundated areas will be severely damaged by more frequency flooding.

Estimates of Economic Effects of Sea Level Rise. A comprehensive economic damage resulting from sea level rise is not attempted for this study owing to the current technical capacity constraints and the lack of sufficient data, time and funding. For these reasons, it is difficult to estimate the economic lost due to sea level rise, such as the damage to infrastructure (buildings, roads, etc), cost of the lost lands etc. However, based on the very rough estimation to the value of infrastructure in the city/town, it is expected that the total economic lost due to sea level rise would be about 21 million US$. Economic loss of other sectors due to sea level rise was not assessed because of data shortage.

VI.3.4. Impacts of Sea Level Rise on Salt Farming in Kampot Province and Kep City

Kampot province has a total land area of 5,209 km^2 with a population of about 528,000 in 1998. The population density in Kampot, in 1998, was about 101 persons per square kilometer. Kampot province and Kep city consist of 8 districts, 95 communes, 476 villages and 2 districts, 5 communes, 16 villages respectively.

Beside fishing and agricultural activity, salt farming is an important economic activity in Kampot province and Kep City. The salt farm activity employs about 4,000 people who are unskilled or low skill and/or are not able to do jobs like fishing or rice farming. It assists rice farmers and/or disable people in raising their annual incomes.

In Cambodia, most of salt production is made in Kampot province and Kep city. Research by Danida (2000) has demonstrated that Kampot province has substantial areas suitable for salt farming. Most of the areas along the beach lay on gently sloping ground making them easily accessible for seawater, which are suitable for salt farming activity. According to Danida, there are six locations for salt production, namely Boeung Rong I & II, Ses Sor, Boeung Touk, Treoy Koh, Kampong Trach and Kep. Among these locations, Boeung Rong I & II are the biggest areas, which produces high amounts of salt (Table 6.6). The production sharply increased by 99.5% from 1995-1996 to 1997-1998.

It is obvious that salt farms in Kampot province and Kep city will be severely damaged by sea level rise as they all are located in low-land areas. Consequently, sea level rise will lead to a serious decline in salt production which, consequently will have negative impacts on employment and other socio-economic conditions in the province. Salt farm facilities might be exclusively destroyed by the sea level rise. The estimate of salt farm's economic loss due to sea level rise is not attempted in this study.

Table 6.7: Salt Production in Kampot Province and Kep City

No	Location	Area (ha)		Production (tonnes)		Distance to Kampot Town (km)
		1995-96	1997-98	1995-96	1997-98	
1	Boeung Rong I & II	1,271	1,452	20,000	54,795	3
2	Ses Sor	300	562	7,070	18,349	6
3	Boeung Touk	320	320	5,000	9,532	8
4	Boeung Koh	990	990	24,000	34,551	7
5	Kampong Trach	540	415	14,000	11,589	45
6	Kep	677	830	6,000	22,953	25
7	Total	4,098	4,569	76,070	151,769	

Source: Danida, 2000.

VI.3.5. Frequency of Flood and Storm

To assess the impact of climate change in coastal areas of tropical countries, an analysis about tropical storms is important. IPCC (1990) reported that the strength and frequency of tropical storms may increase due to climate change. This means that more flooding may occur as a result of the climate change which will give rise to infrastructure damage such as buildings, roads, ports, etc. Records of tropical storms from 1991-2000 showed a total of 36 cyclones with the maximum number occurring in 1993 (Table 6.8). In Cambodia during tropical cyclone Linda that occurred in November 1997, it was recorded that 5 rainy-days occurred consecutively with approximately 400 mm of rainfall. Wind speeds in Kampong Som reached 60 m/s (about 86 km per hour). This storm caused serious damages for many sectors in Cambodia including agriculture, fisheries and transport. However, it is difficult to estimate what would be the likely change in frequency and intensity of tropical cyclones under a changing climate. Therefore, a precise estimate of the economic loss due to floods or storms under changing climate could not be made.

Table 6.8: Yearly Variation of Tropical Cyclone in Indonesia, 1991-2000

Year	IDNo	Extreme TCs	Name of ExTCs	Period of record	Date of ExTCs
1991	25	1	TY FRED	August 11-29,1991	-
1992	24	2	TY CHUCK	June 24-30,1992	-
			TY ANGELA	October 21-30,1992	-
1993	28	9	STS KORYN	June 20-28,1993	June. 28
			TY LEWIS	July 07-13,1993	July 10-11
			TS TASHA	August 17-28,1993	August 21-22
			TS WININA	August 14-30,1993	August 29-30
			TS BECKY	Sep. 17-18,1993	Sep. 18
			TS KYLE	Nov. 20-24,1993	Nov. 23-24
			STS LOLA	Dec. 02-09,1993	Dec.08-09
			STS MANNY	Dec. 21-27,1993	Dec. 25-27
			STS NELL	Dec. 21-Jan.01,1993	Dec.29-Jan.01
1994	34	5	STS OWIN	April 01-08,1994	April 07-08
			STS RUSS	June 04-10,1994	June 09-10
			TS VANESSA	July 07-11,1994	Jul-11
			TS LUKE	Sep. 08-13,1994	Sep. 12-13
			TY TERERA	Oct. 16-27,1994	Oct. 25-27
1995*	16	3	STS GARY	Aug. 26-Sep.01,1995	August 29-31
			STS LOIS	August 27-31,1995	August 29-31
			TS TED	Oct. 09-10,1995	Oct. 10
1996	25	4	STS FRANKIE	July 20-25,1996	July 23-25
			TS NIKI	August 17-24,1996	August 23-24
			TY SAILY	Sep. 04-10,1996	Sep. 10-11
			TY WILLIE	Sep. 10-24,1996	Sep. 13-24
1997	27	4	TS VICTOR	July 31-Aug.04,1997	August01-03
			TS ZITA	August 21-23,1997	Aug-22
			STS FRITZ	Sep. 23-24,1997	Sep. 25-26
			STS LINDA	Nov. 01-04,1997	Nov. 02-03
1998	16	5	TS CHIP	Nov.12-15,1998	Nov.14-15
			TS DAWN	Nov.18-21,1998	Nov.21
			TS ELVIS	Nov.23-26,1998	Nov.27
			TS FAITH	Dec.10-15,1998	Dec.14-15
			TS GIL	Dec.10-12,1998	Dec.11-12
1999	23	2	TY LEG	April 27-May 01,1999	April 29-30
			TY MAGGIE	June 01-08,1999	June 03-09
2000	11	1	TS KAEMI	August 21-23,2000	August 21-23

Source: Department of Meteorology, 2001.

VI.4. Response Strategies and Adaptation

A 1m rise in sea level will have significant and profound effects on the economy and on the living conditions of the population in the coastal zone. It is predicted that a 1m rise in sea level will inundate some parts of the Cambodian coastal zone and Koh Kong province will be affected more severely because most human settlements and most of the economic activities in this province are concentrated in the low-lying coastal area. Tourism and wildlife habitats would also be seriously affected.

The potential impacts of climate change on the coastal zone, particularly on Koh Kong’s coast could be mitigated if adequate planning for responding to such a phenomenon is considered and well prepared. The urgency response depends on how the community would respond. According to the IPCC, three broadly distinct response strategies to sea level rise have been identified. These strategies include retreat, accommodation, and protection. The strategy chosen depends on national circumstances, including the economic and ecological importance of the coastline, technical and financial capabilities, and the legislative and political structure of the countries concerned.

In terms of adaptation to sea level rise impacts, a number of integrated approaches should be implemented as soon as practicable. Public awareness should be taken into account as it is a cost effective means of reducing future expenditures related to sea level rise matter. In other words, people living surround the low land areas in the coastal zone should be informed of the risk that is threatened by sea level rise. The occurrence of climate extreme events in the past could be used as an analogy. The knowledge of community to cope with current extreme events (e.g. severe floods formed by high tide and high river flow in rainy seasons) should be enhanced by setting up a master plan for the coastal zone and action programs. This would help them to adapt to the possible damaging effect of climate change.

VI.5. Conclusion and Recommendations

As a worldwide phenomenon, climate-induced sea level rise is likely to cause significant losses in land and capital endowments in many regions simultaneously. The imminent biggest impacts that could take place were erosion and wetland submergence. Response measures to sea level rise are not an easy task for a state facing this potential problem, in particular for developing countries like Cambodia where financial, technical and institutional capacities will remain major constraints to address this kind of issues for many years to come. In order to evaluate adaptation options efficiently and effectively, it requires a full understanding of the potential impacts and sufficient time to conduct site-surveys. This study is the first attempt to introduce policy makers and the general public to the issue of sea level rise and its potential impacts. It gives some ideas of the potential extent of the impacts and what actions or measures will be required to respond to the problem.

The effect of the rise in sea level by less than one meter on land use could not be detected due to the low resolution of the elevation map used. However, the study showed that if the sea level increases by one meter, many coastal areas will be inundated, and Koh Kong province will be severely affected. A total area of approximately 44 km^2 in this province would be under sea water permanently (0.4% of the total area of Koh Kong Province). The mangrove ecosystem is the widest area that would be inundated and about 56% of settlement area (city/town) would also be flooded. The economic loss from the damage to infrastructures in the city would reach 21 million US$.

Considering that the possible impacts of sea level rise on coastal zone would be very significant to the country, the government should:

1. Develop a national strategic response to sea level rise for the coastal areas;

2. Investigate further potential impacts of sea level rise on biogeophysical, socio-economy, marine resources, freshwater, infrastructure, human settlements, and agricultural production;
3. Formulate a comprehensive adjustment and mitigation policy for sea level rise in the context of integrated coastal zone management;
4. Develop computer-based information systems covering the results of surveys, assessments and observations in order to minimize the impact of sea level rise resulting from climate change;
5. Increase public awareness on the effect of sea level rise on the Cambodia's coast;
6. Identify potential donors either multilateral or bilateral sources to assist the country in adaptation to sea level rise; and
7. Establish cooperation frameworks, training, technology transfer, surveillance of climate change in case of sea level rise, and the sharing of experiences to assist the government in establishing preparedness response to climate change.

VI.6. REFERENCES

Asian Development Bank, 2000. *Coastal and Marine Environmental Management in the South China Sea, Phase 2: Sub-regional Coastal and Marine Environmental Management Database*. Phnom Penh, Cambodia.

Asian Development Bank, 1996. *Coastal and Marine Environmental Management for the Kingdom of Cambodia* (final draft). Vancouver: EVS Environmental Consultants Ltd.

Bann, C., 1996. *An Economic Analysis of Alternative Mangrove Management Strategies in Koh Kong Province, Cambodia: A Research/Training Project in Environmental Economics*. Phnom Penh, The Economy and Environmental Program for Southeast Asia.

Benioff, R.; Guill, S.; & Lee, J., 1996. *Vulnerability and Adaptation Assessments*. The Netherlands, Kluwer Academic Publishers.

Danida & Ministry of Environment, 2000. *Environmental Management of the Coastal Zone: Salt Farming in Kampot Province and Kep Municipality*. Phnom Penh, Cambodia.

Danida & Ministry of Environment, 2000. *Training Notes for Environmental Management: Water and Environmental Aspects* (Part 1). Phnom Penh, Cambodia.

Darwin, R. F. & Tol, R. S., 1999. *Estimates of the Economic Effects of Sea Level Rise*. Retrieved May 16, 2001 from http://www.survas.mdx.ac.uk/publica2.htm

Dixon, R. K., Guill, S., Mkanda, F. X., & Hlohowskyj, I., 1996. *Vulnerability and Adaptation of African Ecosystems to Global Climate Change* (Vol. 6, No. 2). Oldendorf, Inter-Research.

Environmental Protection Agency's Office of Wetlands, Oceans, & Watersheds, 2000. *Coastlines: Sea Level Rise-Response Planning in Maryland*. Retrieved June 18, 2001 from http://www.epa.gov/owow/estuaries/coastlines/dec99/sealevel.html

European Commission & Ministry of Environment, 1997. *Questionnaire Survey and Provincial Waste Generation Report*. Phnom Penh, Cambodia.

Friends of the Earth, 1997. *Going Under: UK Coastal Habitats Threatened by Sea Level Rise*. Retrieved June 8, 2001 from http://www.foe.co.uk/pubsinfo/briefings/html/19971215150205.html

Gommes, R. & Guerny, J. Du., 1998. *Potential Impacts of Sea Level Rise on Populations and Agriculture*. Retrieved April 27, 2001 from : http://www.fao.org/waicent/faoinfo/sustdev/Eldirect/Elre0045.htm

Ministry of Environment, 1995. *Cultural Context of Natural Resource Management in Koh Kong Province*. Phnom Penh, Cambodia.

Ministry of Environment, 1996. *Potential Coastal and Marine Environmental Management Project in Cambodia*. Phnom Penh, Cambodia.

Ministry of Environment, 1997. *Mission Report Survey in Koh Kong*. Phnom Penh, Cambodia.

Monineath, V., & Nissay, S., 1999. *Environmental Management of Coastal Zone Project in Cambodia: Preliminary Assessment Projects Tourism Case Study Kep Resort City*. Phnom Penh, Ministry of Environment.

National Institute of Statistics, 2000. *Cambodia Statistical Yearbook 2000*. Phnom Penh, Ministry of Planning.

National Institute of Statistics, 2000. *General Population Census of Cambodia 1998: Analysis of Census Results*. Phnom Penh, Ministry of Planning.

Nicholls, R. J. & Vega-Leinert, A. C., 2001. *Survas Methodology*. Retrieved May 16, 2001 from http://www.survas.mdx.ac.uk

Thieler, E. R. & Hole, E. S., 1999. *National Assessment of Coastal Vulnerability to Sea Level Rise: Preliminary Results for the U. S. Atlantic Coast*. Retrieved May 16, 2001 from http://woodshole.er.usgs.gov/epubs/openfiles/ ofr99-593/index.html

Vicheth, P., 1996. *Coastal Zone Management in Cambodia*. Phnom Penh, Ministry of Environment.

Vicheth, P., Pich Samang, P., Woodsworth, G., & McNamee, P. J., 1995. *Coastal and Marine Environmental Management in Cambodia: Status and Issues*.

Williams, S. J.; Dodd, K.; & Gohn, K. K., 1995. *Coats in Crisis*. CO, United States Government Printing Office.