Meeting Climate Change Challenges in Transboundary Basins:

Role of Sciences

Edited by

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PREFACE

United Nations University has been long involved with international river basin research to facilitate riparian countries in international river basins to establish a range of actions to enable them to cope with global changes. It is well known that in many international river basins development efforts in the downstream are disconnected from those in the upstream and vice versa. Further gaps exist in preventing information from flowing up to government decision makers, down to affected communities, and across national boundaries. In order to address these gaps, the United Nations University in Collaboration with its partners in Asia have organized a series of discussion workshops which paved the way to two transboundary symposiums, the International Symposium on 'Role of water sciences in Transboundary River Basin Management', in Ubon Ratchathani, Thailand (http://www.mekongnet.org#Preface) and the International Symposium on transboundary Water and Environment Security for Asian International Rivers in Yunan Dali city, China (http://www.mekongnet.org/Dali#Background) and the establishment of a Research Network to discuss the water management issues by researchers and practitioners in all riparian countries to enable information exchange and learn from each other as an open forum. An executive committee of the network has identified 'Water Security', 'Flood Disaster Reduction' and 'River Ecology' as three priority areas that need to be focused in the coming years.

Under the umbrella of transboundary cooperation several research activities have been carried out. This volume presents a collection of research papers in the three priority areas of the research network. An effort was made to include papers on understanding climate change impacts from observations and model studies that would lead to identifying strategies for adaptation to climate change at regional scale.

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The United Nations University

FOREWORD

Understanding, managing and solving transboundary water problems are complicated issues that need multidisciplinary approaches. Like any other international issue, transboundary problems also are essentially interwoven with international politics and national policies. Often, the interpretation of resource availability and sharing differs across boundaries due to different perceptions, values and lack of communication. In order to build consensus, it is necessary to start at a basic framework of resources availability and sharing methodologies across borders. It is here that scientific researchers should provide the much-needed rational framework against which development needs, national goals, political aspirations, cultural issues, etc., and can be evaluated. While the emergence of a framework does not necessarily by itself solve the transboundary issues, it represents an essential ingredient in decision-making.

In many parts of the globe, particularly, in Asia, the quality of data lags significantly behind the advancement of models. This leaves significant gaps in model calibration and evaluation process, allowing the emergence of 'different realities' on the same hydro-environmental problem, depending on the modeling tools used.

Today, more than ever, it has become important to improve the usability of modeling tools, in the professional context: This means, 1) improvement of available data sources, their cataloguing and accessibility, 2) Development of techniques which allow the intercomparison of various data sources and models that are fundamentally different in dimensional (spatial and temporal) context (e.g. Comparison between point scale reengage records and distributed, large-scale rainfall forecasts using atmospheric models) and 3) Development of frameworks that allow to bring all available tools (models plus data) to a unified framework that makes the calibration, intercomparison and use of the resources more efficient. The results of different models will never be the same (they need not to be so), but it is imperative to understand why there are differences and what is the range of possibilities that should reasonably considered as the scientific input to the political process of transboundary corporation and problem solving.

Development in basin scale modeling provides an improved understanding of basin wide water cycle and valuable information to decision makers on water management and disaster risk reduction. Now these methodologies need to be expanded not only to assess future scenarios under climate change, but also to develop appropriate adaptation strategies. Climate change adaptation is generally treated as local actions to be taken to mitigate adverse impacts on livelihoods and environment. However, climate change need not be limited to those negative impacts only. Change also provides opportunities for positive development. Feasible regional adaptation strategies need to be investigated that would maximize basin wide benefits while minimizing adverse impacts.

For example, annual flooding is a regular and essential part of life in many parts of the basin, with the floodwaters bringing positive or negative impacts depending on the extent and duration of each season's flood event. Upstream/downstream coordination can enhance the benefits and reduce losses in a future climate expected to be characterized by increased rainfall intensities. While excessive temperature rise would decrease rice yield, simulation studies also show increasing rice production potential under warmer climate in some parts of the basin. How can these benefits maximized?

Clearly, the impacts of climate change on the complex ecology of the basin are diverse and interrelated, and require further investigation to elucidate them and determine the effects on the population, livelihoods and the economy of the region. By improving the knowledge on the potential impacts, it will be possible to increase the ability to not only improve capacity of people of the region to confront such impacts but also develop regional strategies with multilateral agreements to by riparian countries to maximize potential benefits of the basin.

The collection of papers presented in this volume is the outcome of UNU-ISP activities in critically examining current state of our knowledge and promoting research and activities to further these concepts towards building equitable development in Asia and the World. I hope these proceedings will provide material for future thought, exchange of information and networking to achieve these objectives.

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Part I

CLIMATE AND ECOSYSTEMS CHANGE ADAPTATION

1

HISTORICAL DEVELOPMENT AND CLIMATE CHANGE IN MONSOON ASIA-MEKONG REGION

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ABSTRACT

Development of human society shows clear step-like-changes, according to the historical divisions since the pre-historical ages. There were several notable changes politically, culturally or technologically, which occurred in association with severe climatic conditions or, in an opposite way, under the profitable influences of certain climatic situations. Societies that adapted suitably to the new conditions could succeed in developing further. Considering the Mekong River's problems, studies related to these points are needed. For the first step of this approach, we should concentrate studies on the state of the Mekong River from the 3rd to 11th century, because of the following reasons: (1) In contrast to many detailed analyses for the last 500-1,000 years, including the little ice age, studies on the first 1,000 years of the last 2,000 years are relatively scarce. (2) During these 1,000 years, there was a worldwide warm period called the "Medieval Warm Period", peaking from the 7th to 10th century. We should learn from the way of adaptation in this age, considering similar effects of the global warming, which is going on at present. (3) It is thought that the climate in the Mekong region is sensitive particularly to monsoon fluctuations, which prevail over Southeast Asia. Lessons for the "Medieval Warm Period" in Southeast Asia, therefore, are important (4) In Southeast Asia, there were several noteworthy developments during the time from 8th to 10th century, which were sustained by the political situations (kingdoms, nations, ethnic groups or political bodies) under relatively stable, prosperous conditions. (5) Examples are: In Indonesia, Borobudur was constructed during the time from about 760AD to 830AD. After 928 AD, the name of Borobudur disappeared in the history completely. In Cambodia, Angkor was built in the 9th century. Barai, big ponds constructed nearby, may indicate some effects of water landscape as well as irrigation purposes, during the unusual dry conditions. In China, the Tang Dynasty from 618 to

907 was the most prosperous age, expanding forces and cultures. In Japan, Yamato Chotei, the central government, was established for the first time. Summarizing the problems mentioned above, the following items are proposed to be studied: (1) Reconstruction of past climate during the time from the 3rd to 11th century. (2) Historical development of human activities together with the age division of Southeast Asia, as a whole. (3) Chronology of hydrological events of the Mekong River, particularly in the time corresponding to the "Medieval Warm Period".

Keywords: History of human activities, Medieval Warm Period, Mekong region, Monsoon influences, Southeast Asia

INTRODUCTION

The relationship between development of human societies and climate conditions has been studied for many years. However, our knowledge is very limited for SE Asia, because the studies were carried on from the standpoint of archeology, history, and climatology separately in almost all cases.

The Mekong region is located in the central part of so-called Monsoon Asia under the influence of seasonally different monsoons circulation. The activities of monsoon change every years and periods in terms of 10 to 100 years or more, which result in climatic changes with fluctuation, trends and occasional severe events of not only temperatures, but also rainfall, floods, drought and other climatic elements.

In order to make clear the relationships between the historical development of human societies and climate changes in the Mekong region, which will contribute to our consideration for future conditions, I try first to describe the previous studies for the whole of Monsoon Asia, concerning the monsoons in particular. The period analyzed is mainly from the 3rd to 11th century, because it includes warm periods with peaks from the 4th to 5th (6th) century and from the 8th to 10th century, corresponding to the Medieval Warm Period in Europe.

I hope that this article will contribute to solving challenges for the Mekong's problems, in where climate conditions will change more apparently under future global warming.

METHODOLOGY

Periods to be studied

To collect, archive and interpret climatic change of the past, in particular in the period proposed, methods are mentioned. First, why should we study the period from the 3^{rd} to 11^{th} century? As has been recognized globally, there were warm periods with the peak from the 8^{th} to 11^{th} century (Lamb, 1977). In East Asia, the warm period started from the 4^{th} century and after then, reached its peak from the 8^{th} to 10^{th} century (Zhu, 1973). This warm period is called "Medieval Warm Period" in Europe and commonly in other parts of the world. In Japan, however, it is generally accepted that the ancient political regime shifted to the medieval in 10^{th} century. Therefore the peak warm period was still in the ancient age (Yoshino, 2009). In Table 1, naming of the warm period from the 3^{rd} to 11^{th} century appeared in the past studies, reports or books.

Based on this Table 1.1, it is concluded that the warm period should be called "Little Climatic Optimum", if necessary.

Evidence

The next questions concerning the warm period are (1) when? (2) how warm? and (3) how long?

In some text books and more recently, in the IPCC Report (2007), it is written that the Medieval Warm Period occurred from the 9^{th} to 13^{th} century, showing numerous Northern Hemisphere paleoclimatic temperature reconstructions. Norse seafaring colonization around the North Atlantic at the end of the 9th century indicated that the regional North Atlantic climate was warmer during medieval times than during the cooler "Little Ice Age" from the 15th to 19th century.

Because paleoclimatic records have become more numerous, it has become apparent that temperatures during the warm period were higher over the Northern Hemisphere than the period during the subsequent "Little Ice Age", and are comparable to temperature in the early 20^{th} century.

The previous studies differ in methodology, and in the underlying paleoclimate proxy data utilized, but all reconstructed results show basically high temperature in the "Medieval Warm Period", cool "Little Ice Age" and sharp increasing tendencies in the late 20^{th} and early 21^{st} century as shown in figure 1.1.

Year used in studies	Naming	Evidences	Authors
1907	Little Climatic Optimum	Central Asia, 9th - 16th centuries, terminating at the beginning of "Little Ice Age"	Huntington (1907)
1977	Medieval Warm Period	Europe, AD 900 - 1300	Lamb (1977)
1978	Little Climatic Optimum	Activity of Viking, AD 400 - 1200, with peak 8th - 11th centuries	Yoshino (1978)
1979	Little Climatic Optimum	A peak at the beginning of 4th century	Yamamoto (1979)
1994	Medieval Warm Period	Citrus trees, cultivation in China	Zhang De'er (1994)
1995	Moslem (Arab)	Warm period around 7th century	Issar (1995)
2000	Little Optimum	Equivalent to "Medieval" Warm Period in Europe	Suzuki (2000)
2005	Medieval Warm Period	Word used in "Encyclopedia of World Climatology"	Yoshino (2005)
2007	Medieval Warm Period	Word used in an international report. AD 950 - 1100 was the warmest period in the last 2,000 years	IPCC (2007)
2007	(Medieval Warm Period)	Lop Nur in China. Results of synthetic studies	(2007) (Xia Xuncheng)

Table 1.1: Naming of the Warm Period from 4th to 10th centuries appeared in the past studies/reports/books

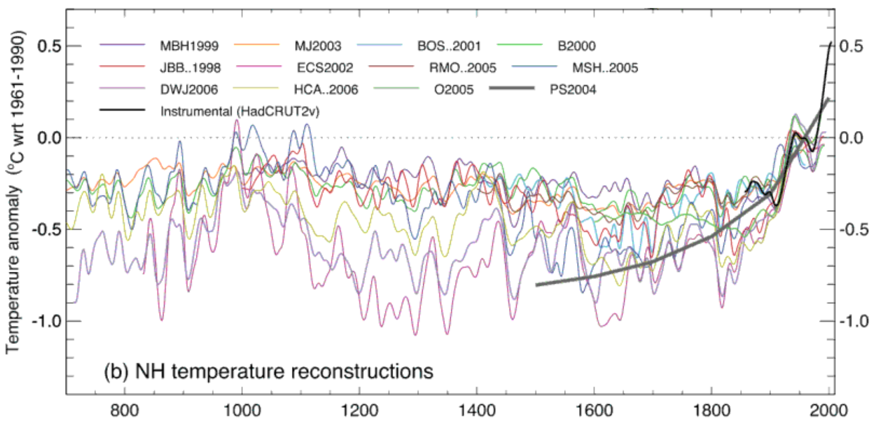

Figure 1.1: Reconstructed Northern Hemisphere temperatures variation (IPCC, 2007)

On the other hand, there is an argument that an estimation of the "Medieval Warm Period" - a long-term spatial homogeneity changes - is premature based on the scattering of data currently available (Esper and Frank, 2009). They stressed the problems of long-term (how long, and when), locations of points obtained data (where), spatial representation (area, region, or hemisphere), scattering (time and space scale) etc. From the viewpoint of the present article, it should also be noted that there was no discussion on the time before the 9th century.

How was the warm period in Southeast Asia? In particular, how was the climatic condition of the warm period in the Mekong region in the 8th to 10th century? Not only temperature, but also drought or aridity conditions should be made clear in SoutheastAsia, including the Mekong region.

Reconstruction methods of the past conditions

In figure 1.2, various methods for possible dating to reconstruct the past conditions of environments, particularly temperature are summarized. Analyses for the period in the last 2,000 years can be done mostly by archeological dating and old document dating. In addition, it should be mentioned that Zhan et al., (2010) presented recently a result of study seen from long year series analyzed by the oxygen isotope ratio in speleothems obtained from Wanxiang Cave, Gansu Province in China, which reflect the variation of monsoon rainfall, and its linkage to Chinese dynastic change.

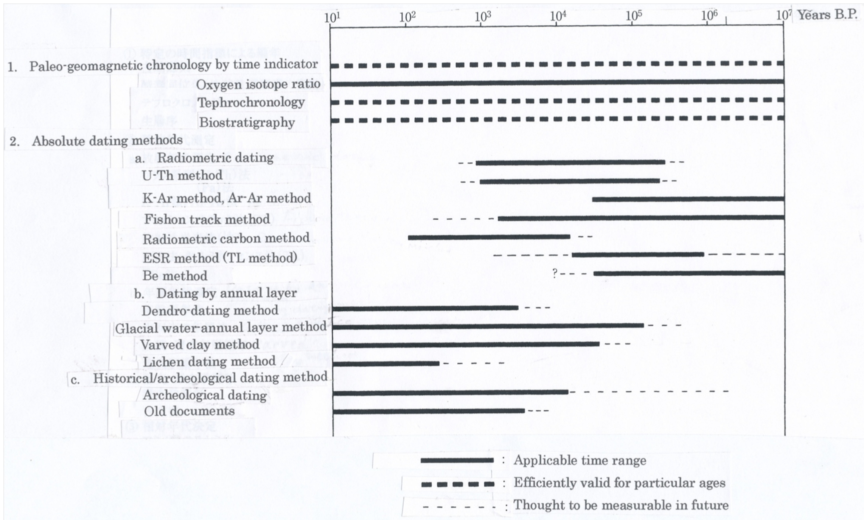

Figure 1.2: Possible dating methods and ages

At the present stage of the studies for the last 2,000 years, dating methods by oxygen isotope ratio as well as by archaeological and by old documents are most useful.

Human activities in SE Asia

In SE Asia, there were several noteworthy developments during the time from the 8th to 10th century, sustained by the political situations such as kingdoms, nations, ethnic groups or political bodies under the influence of relatively stable, favorable environments, particularly climate conditions. Some examples are as follows.

- In Indonesia, Borobudur was constructed during about 760AD to 830AD. After 928AD, the name of Borobudur disappeared from history completely.
- In Cambodia, Angkor was built in the 9th century. Big ponds called Barai were constructed nearby for the purpose of irrigation, but it is thought that there were some effects on water landscape as well as the so-called oasis effects during the unusual, extremely hot, dry seasons. Details will be mentioned later.
- In northeast Thailand, Dvaravati culture supported by Buddhism developed since the 6th century until the early 11th century, when the Khmer invaded from Cambodia. Dvaravati culture was economically developed by iron-smelting and salt-making industries (based on evidence found as mounds in the archaeological sites),

but which resulted in heavy deforestation for firewood. After the 13th century, evidence suggests that these industries retreated because of deforestation and the decline of the Khmer Kingdom, caused by invasion of Champa in south Viet Nam (Nitta, 1991, 1994, 1999). For the changes in northeast Thailand, it is thought that the climatic conditions strengthened positively forest development in the early stage, but negatively at the later stage, because of too much demand for wood resources. Barai in northeast Thailand should be analyzed and compared with those in Cambodia, in relation to climate change, as well as irrigation and religious purposes (Srisakra, 1999).

- In China, the Tang Dynasty from 618AD to 907AD was the most prosperous age, expanding forces and cultures. Since the early 20th century, it has been pointed out that the Arab Empire reached its maximum extent in the 9th century by connecting the routes between Europe and East Asia (East, 1938). Linkages between climate change, in particular, monsoon rainfall, and human, social activities in China during the historical age were studied recently, including the periods under discussion (Zhang et al., 2010).
- In Japan, Yamato Chotei, the central government, controlled the western part of Japan gradually in the 4th century. In the 5th century, the area expanded further based on stable agricultural production. The central government intended to shift northward the power front in Honshu during the 7th to 9th century (Yoshino, 2009a), which will be described later again.

Assessment of impacts and adaptation to climate change has been summarized for the countries in Asia among the worldwide project (International START Secretariat et al., 2007), but only the countries of Thailand, Laos and Viet Nam were selected for study and items under discussion were not taken into consideration. We should collect more examples in the countries and regions of South, Southeast, and East Asia for the purposes discussed in this article. As has been reported (Ito, 1999), dry conditions in the continental part of Southeast Asia played an important role in developing cotton production in the 6th to 9th century. Such a viewpoint is necessary for further studies.

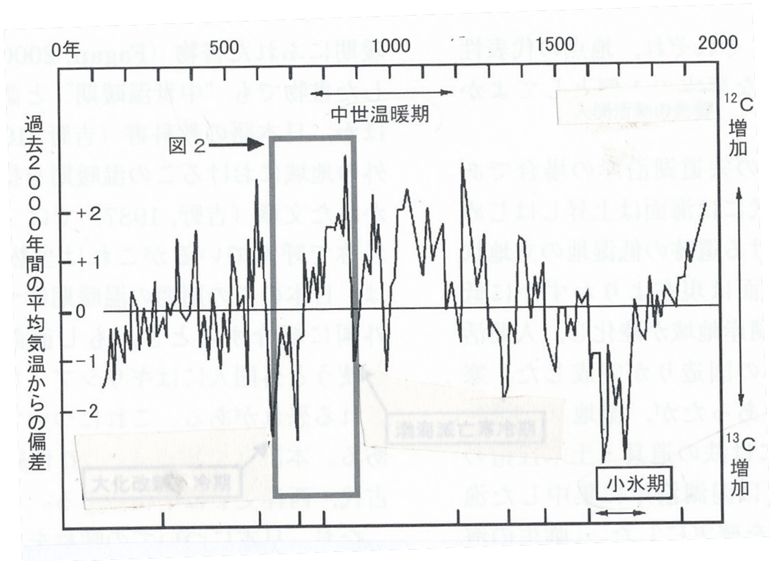

Figure 1.3: Air temperature fluctuation during the historical period revealed from carbon isotope ratio of tree rings of Japanese cedar at Yaku-island(Kitagawa, 1995a, b) and naming of the warm and cold periods(Yasuda, 2004)

CLIMATE CHANGE AND HUMAN ACTIVITY IN THE HISTORICAL AGE

Japan

In figure 1.3, air temperature fluctuations are shown, based on the carbon isotope ratio of tree rings of Japanese cedar (Kitagawa, 1995 a, b), which identifies the warm and the cold periods (Yasuda, 2004). In figure 1.4, air temperature fluctuations during the period from about 620AD to 900AD (also part of figure 1.3), are revealed from carbon isotope ratios of tree rings of Japanese cedar at Yaku-island, south of Kyushu, southwest Japan (Kitagawa, 1995 a, b). It also shows the occurrence rate of natural hazards in the inland part of the Kinki-district, central Honshu, Japan (Nakatsuka, 1995; Yasuda, 2004). They show close fluctuation patterns.

In Japan, the natural environment has become favorable at the end of the 6th century. As has been mentioned, Yamato Chotei, the central government, was established in the central part of Honshu, in the 7th century. Missions between China (Tang Dynasty) and Japan were exchanged rather periodically and culture from China came into Japan directly and through the Korean peninsula indirectly (Yoshino, 2009b).

Figure 1.5 shows a northward shift of forts or fences in the Tohoku District in the period from the 7th to 9th century, which was illustrated

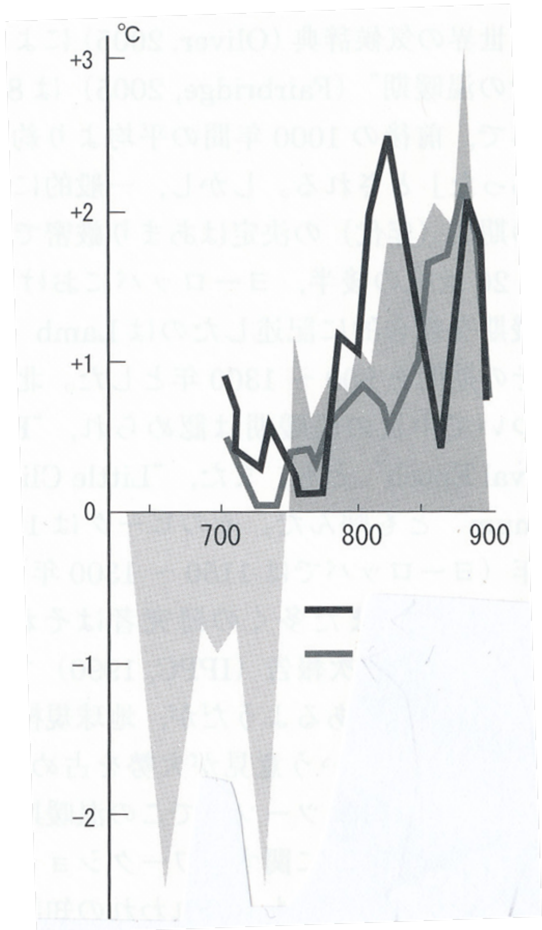

Figure 1.4: Air temperature fluctuation (a part of Fig.3) revealed from carbon isotope ratio of tree rings of Japanese cedar at Yaku-island (Kitagawa, 1995a, b) and occurrence rate of natural hazard in the island part of the Kinki-district (Nakatsuka, 1995; Yasuda, 2004)

Figure 1.5: Northward shifting of forts or fences in the Tohoku District in the period from the 7th century to the 9th century. Map by Yoshino (2009), referring to the map by Takemitsu(1994).

by Yoshino (2009a), referring to the map by Takemitsu (1994). It is shown that the northward shift of the power front of the central government, Yamato Chotei, during the 7^{th} to 9^{th} century occurred about 70-80 years earlier in Dewa, an ancient state on the Japan Sea side, than in Mutsu, also an ancient state on the Pacific side, Tohoku district, north Honshu. These facts may be originated from the immigration pressure from the south, central Japan, and the resistance power of the northern groups. It is interesting to note, however, that the speed of the northward shift was almost the same on both sides, which can be attributable to the influence of warming on the broader space scale.

As a second example in Japan, I introduce the settlement size changes in Boso Peninsula, southern part of the Kanto district, central Japan. Figure 6 shows the climate changes estimated by Yoshino and the changes of the settlement size found at 18 sites in Chiba during the period of double cropping from the 5th to 11th century (Kurita, 2001). The settlement size developed at the end of the 8th to the middle of the 9th century, the peak period. Roughly speaking, they are included almost during the period from the 6th to 10th century, corresponding to the warm period.

Cambodia

Angkor is the best example in Cambodia. It was established by the "Funan" in south Cambodia in the 1st century. The high period of the Funan Empire flourished about the 1st to 6th century with a peak at around 500AD. The oldest known inscription on a monument in Khmer in 611AD was found. A small empire was established in Angkor (Chenla) in about 770AD. In 802AD, Angkor, the Khmer Empire, entered the golden age.

In 877AD, the capital Harihararya was constructed with a large reservoir, East Barai (Idratataka), whose size is 0.8 km from south to north, and 3.8 km from east to west. The area of surface water is 300 ha, irrigating 5,000 ha of land. It is thought that these values indicate countermeasures for water shortage in the dry season considering double cropping.

In 889AD, the capital of Angkor Empire was established in Yashodrapula and in the period 929-942AD, moved to Chok Galgyar, 90 km northeast of Angkor. In 944AD, it became a unified nation. In 1113AD, Angkor Wat was built. In 1177AD, the Chamba army occupied Angkor cities. In 1181AD, construction of Angkor Tom began. In 1190, Angkor Kingdom ruled Chamba. The boundaries at the beginning of the 13th century were: west was the Menam Basin, north was southern part of Laos and east was Middle Vietnam. Building Angkor Tom was finished also in the 13th century. In the 14th century, Sham army invaded Angkor, resulting in gradual decline (Ishizawa, 1996). These facts shows that the time of development of Angkor had closely with the warming period with a peak of the 8th to 10th century.

In addition, reservoirs in the Angkor region are worth studying. As mentioned above, East Barai was constructed during 877AD and 889AD. It is said that the depth of water was 3-5 m usually and did not dry-up by to 1 m depth. However, in the 11th century, East Barai was dried-up. Instead, West Barai was completed in the 11th century measuring 8 km (east-west) and 2.2 km (south-north). Its water storage was 42,000,000 cubic m, having a surface water area of 1,400 ha. This planning could be acceptable for irrigation as far as the amount of water is concerned. However, actual problems occurred on the following points: (1) Areas surrounding Angkor were almost exploited; (2) Because of gentle inclination of the land, deposition of sands and soils occurred fast; (3) Irrigation ability needed for development of agriculture has already reached its peak; and, (4) Hydraulic society reached its limit of development. As a result, there was a tendency towards gradual decline.

PROPOSAL AS CONCLUSION

Summarizing the problems mentioned above, the following items should be studied:

1. Reconstruction of past climate, particularly, floods and droughts during the time proposed.
2. Historical development should be studied as a whole together with the various periodic ages of Southeast Asia.
3. Chronology of hydrological events of the Mekong River regions, particularly in the time corresponding to the "Medieval Warm Period".

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2

OBSERVATION OF CHANGES OF WATER CYCLE IN MEKONG: A RESEARCH PROJECT FOCUSED ON FOREST AREA

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ABSTRACT

A few projects related to the water cycles of Mekong River Basin were started in early 2000s with the Forestry Administration, Cambodia. The permanent study fields have been set up and soils, ground water level, stem flow as well as meteorological data have been continuously measured since 2002. The weather observation tower with 60 meters height was constructed in October 2003 in evergreen forest area in Kampong Thom Province, central Cambodia. And a new tower with 30 meters height was constructed in October 2009 in deciduous forest area in Kratie Province, central-east Cambodia. Vertical profiles of environmental parameters in these forests have been observed. In addition to these ground observation, monitoring by satellite remote sensing and observation network formation were launched. In order to investigate vegetation, forest structure, and leaf phenology, a 80 m x 30 m quadrat plot was set up so as to cover a micro-topographic variation near tower site. The soil thickness near the tower site was changed from 30 to 230 cm. The average soil thickness was about one tenth of that of typical evergreen forest at the typical deciduous forest near this tower site. Monthly and annual fluctuation of precipitation influenced very much on soil water content and water storage capacity. The observation of water cycle was conducted in the evergreen forest watersheds in Kampong Thom province. The stable isotope analysis was performed for rainfall and stream flow in four watersheds. All stream water residence times for the four watersheds were shorter than the residence time of the groundwater through the soil and regolith layers. Evapotranspiration rate was estimated by Bowen ratio method. It is larger in dry season than in rainy season. Surface conductance was estimated in an evergreen forest in late dry season and rainy season. A

new system named DS4 was developed to detect anomalous changes of land cover by introducing the discrete state space model combined with symbol string processing to MODIS satellite data. The DS4 effectively collects the characteristics for vegetation conditions (ex. phenological changes) as well as land cover changes.

Key words: the Mekong River Basin; Climate change; Forest; Remote Sensing; Seasonal Change; Ground observation system

INTRODUCTION

The forest meteorological towers with 60m and 30 m high and wells for underground water measurement were constructed and many new instruments are monitoring environmental conditions at an evergreen forest and deciduous forest in Cambodia since 2003 and 2009 respectively. The activity is strengthened under the project "Establishment of the Integrated Forest Ecosystem Observation Sites and Network in the Lower Mekong (2008-2011)" funded by the Ministry of Environment of Japan. Although the problem in tropical forest has been widely concerned, deforestation and forest degradation is still a hot issue in the world. In most of the countries in South East Asia, scientific knowledge about forest ecosystem and forest law enforcement are not enough to maintain the forest in good condition from the natural environment preservation point of view.

METHODOLOGIES

Studies at the Intensive Study Sites

Being under the influence of seasonal monsoon and the local topography, various types of natural vegetation are observed in the Mekong River Basin. Vast areas are well covered with luxuriant forest which can be classified into two main types of evergreen forest and deciduous forest. Evergreen forest can be classified into tropical rain forest, semi-evergreen forest, hill evergreen forest, pine forest, mangrove forest swamp forest and beach forest. Deciduous forest can be classified into mixed deciduous forest, dry dipterocarp forest and savanna forest.

In order to investigate vegetation, forest structure, and leaf phenology, a 80 m x 30 m quadrat plot was set up so as to cover a micro-topographic variation (flat, hill, and shallow valley) near tower site. Within the quadrat, all trees > 5 cm DBH were enumerated, with each tree being measured DBH, major and minor axes of crown, tree height, and height of the lowest living branch, noted for position, and identified to species.

To estimate the stream water residence times of the watershed, the stable isotope analysis was performed for rainfall, stream flow from four watersheds named O Toek Loork (area:4km^2), O Thom I (area:137 km^2), O Thom II (area:126 km^2), Stung Chinit (area:3,659 km^2) and groundwater at Bak Snar located lower than watersheds.

To estimate evapotranspiration in the forested area, the combination of meteorological observation tower and interception plot is used. Net radiation, short wave radiation, wind speed, wind direction temperature and humidity are measured every 10 seconds and recorded the average value in every 10 minutes. Rainfall, through fall and stem flow are collected at both tower sites. The interception plots are set up in the forest around the towers. The heat balance method incorporated with Bowen ratio is used to calculate the evapotranspiration.

Surface conductance was estimated for an evergreen forest in central Cambodia in the late dry (May) and rainy (August) seasons, and the effects of environmental conditions on surface conductance were compared among seasons.

Forest Information of the Whole Mekong River Basin by Satellite Remote Sensing

Global environment affects the trend of seasonal changes of these forests. Therefore remote sensing technology is introduced for observing the seasonal changes in this region for twenty years. The combination of NOAA and high resolution satellite, ex. Landsat data, must be useful to differentiate environmental changes and land use changes caused by direct human activities. The final objective of this study is to obtain recent qualitative changes in forested area in the Lower Mekong.

Remote sensing technology is considered one of the useful and important tools for monitoring various forest conditions in the world. However, appropriate monitoring system using remote sensing is not yet clear. Sader et al. (1990) suggested that higher resolution sensors (MSS, TM, SPOT, aircraft scanners and mapping cameras) are necessary tools to record the spectral and spatial details needed to link intensive ecological field studies to the forest community and biome levels. Even though these ideas on multi-stage observation are considered quite useful for studying environmental conditions, most of the activities could get limited results because of the remote sensing data which are obtained "by chance" depending on cloud cover and other problems.

While remote sensing data give us various data of the ecosystem related to the electro-magnetic reflectance and/or radiation, it is necessary to find the appropriate "remote sensing indices" for monitoring forest environment conditions. The phenological changes of ecosystem are greatly related to the changes of natural environment, such as water, temperature, soil and solar radiation. Therefore, "appropriate remote sensing indices" shall reflect the environmental conditions. We studied to get information about seasonal changes of environmental conditions by remote sensing data. Various researches on global environment study utilize frequent observation satellite data. The NOAA-AVHRR and SPOT/Vegetation are commonly used for such purpose (Ricotta et al., 1999) and "the ten-day composite images", which are created by choosing the best data in ten days for every pixel, are often used to monitor seasonal changes of terrain conditions (Defries et al., 1994). However, the influences of cloud and haze still remain in those data and it makes difficult to monitor phenology with 10 days interval (Roerink et al., 2000). On the other hand, the "monthly" composite data to reduce the influence of noises are not appropriate for following phenological aspects because most of the dynamic seasonal changes of vegetation occur within a few weeks (Viovy et al., 1992).

Therefore, the authors developed the processing method named LMF (Local Maximum and Fitting) and LMF-KF (Local Maximum and Fitting with the Kalman Filter), which modeled the seasonal changes for time series data of frequent repeat observation satellite data. The LMF-KF introduces the form of the sum of cyclic functions with time-dependent coefficients (Sawada et al., 2005) and produces clear images with 10 days interval. We applied these techniques to SPOT-Vegetation data to detect snow cover area and NOAA-AVHRR data to reveal the environmental conditions in the Mekong River Basin. These methodologies give us the opportunity to monitor environmental conditions of forest area in both global and national scale, which will help us monitoring with rather high spatial resolution satellite. We think that it will give us an ideal system for multi-stage monitoring as well.

Tree species (DBH > 5cm)	Count [0.24 ha-1]
Dipterocarpus tuberculatus	33
Terminalia tomentosa	18
Shorea siamensis	15
Shorea obtusa	8
"PON TA LAY"	8
Xylia xylocarpa	7
Mitragyna speciosa	6
Dalbergia nigrescens	3
Others	7
Total	105

Table 2.1: Tree species at the plot of the deciduous forest

RESULTS AND DISCUSSION

Studies at the Intensive Study Sites

Forest Species diversity and site environment

The deciduous forest was characterized by a small tree density (ca. 5 trees per 10 m x 10 m subquadrat), low tree height (9.5 m on average) and a few dominant deciduous species: Dipterocarpus tuberculatus and Shorea siamensis (Dipterocarpaceae); and Terminalia tomentosa (Combretaceae). The three species contributed 63 % of trees within the quadrat. Deciduous dipterocarp Shorea obtusa was also found (Tani et al. 2007). The tree species composition indicated that the forest was similar to dry (or deciduous) dipterocarp forest widely distributed in Thailand (Smitinand, 1977).

On the flat surface of western part of the site, typical plinthosols that had plinthites from -30 to -80 cm; below -80 cm, relative soft soils which contained much clay were distributed (Toriyama, 2007). At that point, soil depth was about 2 m. On the shallow valley of eastern part of the site, sandy soils are found from the surface to -30 cm and fine roots concentrated (Ohnuki, 2008a, 2008b). The soil thickness near the tower site varies from 30 to 230 cm; it was so shallow on the small hill and basaltic rocks are partly exposed.

Estimation of stream water residence times of the watershed

In the dry season, δD values in stream water were very steady and close to the weighted mean of δD in rainwater (–43.9 %) In the rainy season,

Tree species	Count [0.24 ha-1]	DBH [cm]	Tree height [m]	Crown cover area [m2]
D. tuberculatus	33	23.3±7.7	10.7±3.2	25.4±16.6
T. tomentosa	18	18.6±5.1	10.5±2.3	13.5±7.9
S. siamensis	15	13.9±5.6	7.7±2.5	10.4±10.4
S. obtusa	8	21.9±7.9	10.1±3.5	20.8±12.1

Table 2.2: The size of trees forming canopy at the deciduous forest plot

δD in stream waters changed in correspondence with the variation in δD of rainwater. The δD in stream water of O Toek Loork showed smaller temporal variation than in the other watersheds. At the Bak Snar Forest Office, the δD values for groundwater had less temporal variation than δD values for stream water.

The residence time was estimated to be 9.4 month for groundwater at Bak Snar. The residence times were estimated to be 7.5 months, 2.9 months, 1.7 months and 3.9 months for stream water from O Toek Loork (area:4km^2), O Thom I (area:137 km^2), O Thom II (area:126 km^2), Stung Chinit (area:3,659 km2), respectively. All stream water residence times (1.7-7.5 months) for the four watersheds were shorter than the residence time of the groundwater (9.4 months) through the soil and regolith layers, implying that the stream waters consisted of not only the groundwater-flow component, but also younger-aged flow components such as saturation-excess overland flow.

Effect of soil drought to evapotranspiration

Evapotranspiration rate was estimated to be larger in dry season (4.6mm day^{-1}) than in rainy season (4.3mm day^{-1}) by Bowen ratio method (figure 2.1). The effects of soil moisture did not show significant differences in seasons. It indicates that soil water drought in the late dry season does not limit transpiration from the entire forest community. Evergreen forests in central Cambodia transpired actively in the late dry season and surface soil moisture was dry to −50 hPa in dry season (figure 2.2). However, the deep soil at 150cm depth was wet even in the dry season. It shows that the forest vegetation uses the deep soil moisture in the dry season.

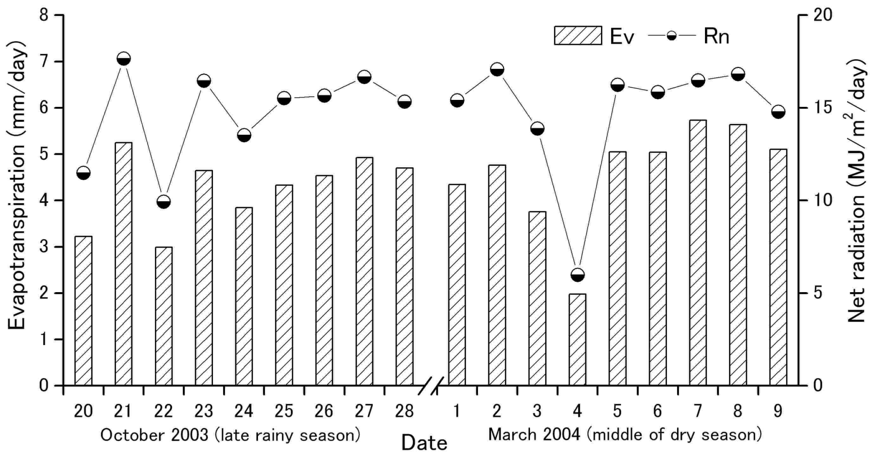

Figure 2.1: Relationship between evapotranspiration (Ev) and net radiation (Rn)

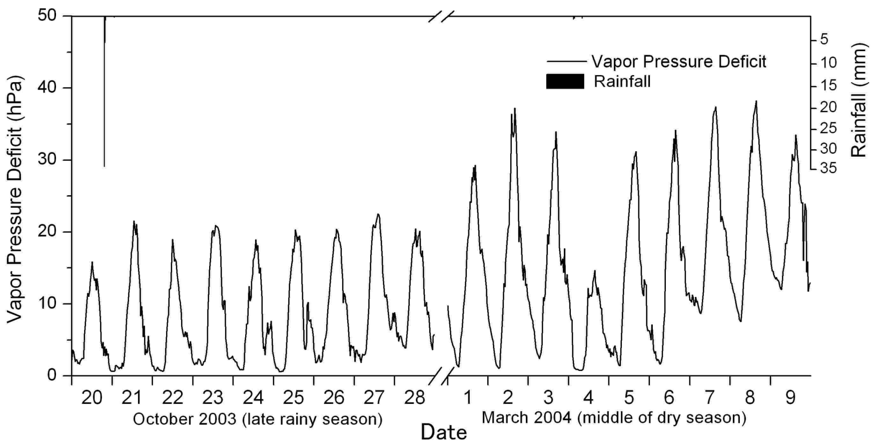

Figure 2.2: Relationship between vapor pressure deficit and rainfall

Forest Information of the Whole Mekong River Basin by Satellite Remote Sensing

We have developed the LMF techniques for time-sequential satellite data, such as NOAA/AVHRR, MODIS and SPOT/Vegetation (Sawada et al, 2005). It could provide us cloud free images for more than 20 years with 10 days interval. Especially NDVI, NDII (as Leaf Water Content Index), and LST (Land Surface Temperature) data are found useful to monitor the environmental conditions of the area. NDVI data sets processed with the LMF technique detected considerable differences in leaf phenology between evergreen and deciduous forests distributed in the lowland seasonal tropical forests of Cambodia. The technique also provided NDVI data, suggesting that leaf loss in evergreen forests is significant and both temporally and spatially heterogeneous. The increases in leaf area due to leaf regrowth were also detected in both deciduous and evergreen forests, and they started in the middle of the dry season (Ito, 2008). The LMF processed data can provide useful information on the timing and magnitude of leaf phenology in the seasonal tropics despite the difficulties with residual cloud contamination.

A semi-automatic system named DS4 was developed to detect forest cover changes by using MODIS satellite data which can observe the same area almost every day. The DS4 introduces the discrete state space model with symbol string processing and detects anomalous land cover changes. The DS4 integrates all the band information and has various effective characteristics for vegetation monitoring, ex. it shows the change level of each pixel separately and takes into account the phenological effects.

To check the effectiveness of the system, 21 sample areas are selected where we had obtained sets of ASTER images which had been taken before and after the land cover changes in Thailand, Laos, Cambodia, and Vietnam. From the comparison between ASTER and MODIS information, MODIS data afforded to identify the date of forest cover changes much better than ASTER data.

CONCLUSIONS

There are tendency that higher trees live on deeper soils and lower trees live on shallower soils. On typical deciduous forest near this tower site, average soil thickness is about one tenth of that of typical evergreen forest; the small difference of micro-topography controlled soil types, soil thickness, soil water content, tree species and tree heights. Monthly

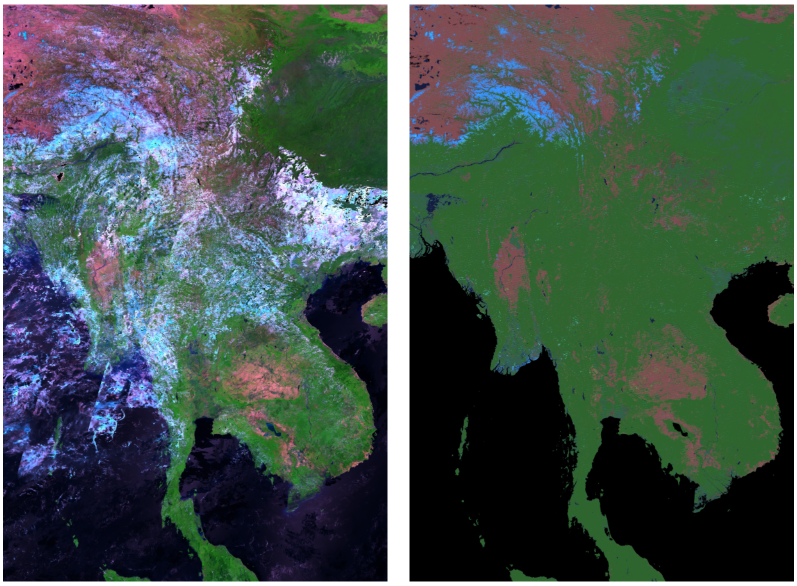

Figure 2.3: Result of time series processing using a discrete model (DS4) left: original image, right: processed and categorized image (original in color)

and annual fluctuation of the precipitation influenced very much on soil water content and water storage capacity.

The residence time (7.5 months) of water in the smallest watershed ($4km^2$; O Toek Loork) was longer than those (1.7-3.9 months) of the other three larger watersheds (126-$3{,}659km^2$),. It suggests that the contributions of the groundwater flow component and the younger-aged flow components differ in the stream water in each watershed. O Toek Loork, located in the headwater area, had poorly developed drainage patterns and a stable regime. Thus, the stream water residence time was relatively long because the contribution of the groundwater-flow component to stream water was relatively large.

Soil water drought in the late dry season does not limit transpiration from the entire forest community. Evergreen forests in central Cambodia transpired actively in the late dry season and surface soil moisture was dry to –50 hPa in dry season. However, the deep soil at 150cm depth was wet even in the dry season. It shows that the forest vegetation uses the deep soil moisture in the dry season.

From the comparison between ASTER and MODIS information, MODIS data afforded to identify the date of forest cover changes much better than ASTER data. It is also a good advantage of the DS4 system that it allows us to process a huge amount of MODIS data (more than 100GB) in a common PC.

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3

CLIMATE CHANGE VERSUS LAND-COVER CHANGE: A COMPARATIVE ANALYSIS IN THE MEKONG BASIN

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Climate change is often mentioned as the main driver of hydrological changes in the Mekong Basin. However, the analysis of rainfall and runoff data, either recorded at several rainfall and level gauges or projected by a regional climate model downscaled for Southeast Asia, provide different conclusions. Rainfall remained stable over the last 5 decades and is expected not to significantly change until 2050 while land-cover changes significantly altered the flow production in a catchment covering 17% of the lower Mekong Basin. This paper summarizes the main research results obtains from three hydro-climatic analysis undertaken from September 2008 to February 2010.

The first analysis aimed at detecting significant trend in rainfall pattern in the central part of the Mekong Basin over the second half of the 20th century. The modified Mann-Kendall trend detection test (Hamed, 2008) was applied to several climate indices derived from daily rainfall recorded at 17 rain gauges in the central part of the Mekong Basin over the period 1953-2004. Results indicate that rainfall did not significantly change in the studied region (panel B of figure 3.1 showing no significant trend in the time series).

The second analysis characterized projected fine-scale changes in the climate over continental Southeast Asia over the period 1960-2049. 24 annual variables capturing the intensity, seasonality and extremes in precipitation and temperature were computed from the PRECIS regional climate model (Jones et al., 2004) downscaled for Southeast Asia by the Southeast Asia SysTem for Analysis, Research and Train-

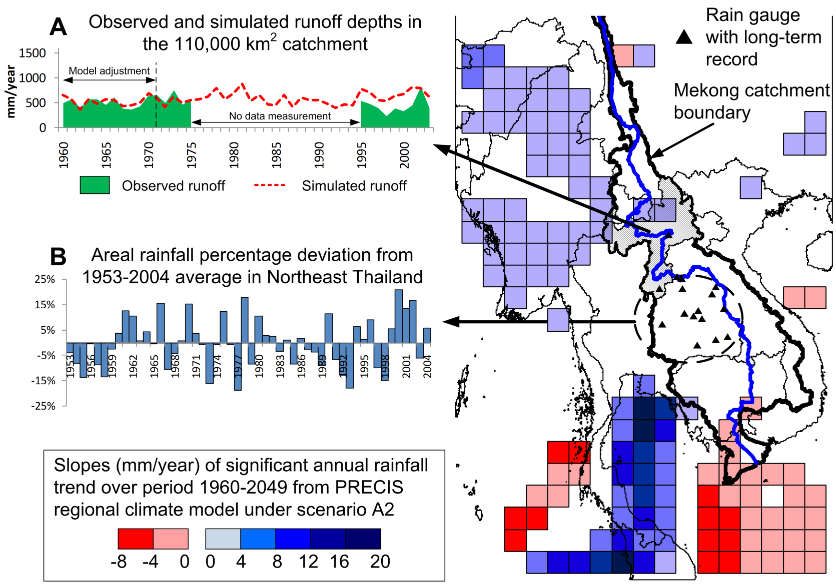

Figure 3.1: Hydro-climatic variability in the Mekong catchment

ing Regional Center. While temperature increases all over the region, changes in precipitation are much sparser and mainly localized outside the Mekong Basin (figure 3.1).

The third analysis assessed changes in the rainfall-runoff relationship in a 110,000 km2 catchments of the Mekong Basin (figure 3.1). Daily rainfall, river flow and pan evaporation data were collected from the Mekong River Commission. Areal rainfall and runoff time series of the catchment were used as input to run the 2-parameter monthly lumped GR2M model (Mouelhi et al., 2006) over the period 1960-2004. Results indicate that catchment water yield decreased from 1995 onward by about 230 mm/year. This change is likely explained by the depopulation of the northern part of Laos where nearly one fourth of the country population successively escaped ground conflicts and the communist takeover from 1965 to the 1980s (Stuart-Fox, 1986; Taillard, 1989). Resettlement policies of the 1990s sustained these emigrations causing the abandonment of large cultivated areas, most likely followed by forest re-growth with higher transpiration rates.

Results from these 3 studies demonstrate that past and projected rainfall is stable in the Mekong Basin Extreme climate events observed over recent years in the central part of the Mekong Basin most likely do not result from any man-made climate changes but rather reflect the natural climate variability. On the other hand, anthropogenic alterations of the land cover appear to have deeply affected catchments' hydrological behaviors through changes in evapotranspiration rates, as previously evidenced by Brown et al. (2005) in other parts of the world. This clearly evidences the notion that climate change, whose impacts remain uncertain, will only be one of many environmental factors contributing to future changes in the water availability and food security (Johnston et al., 2009). Therefore, it is crucial that projections of river flows do not rely on greenhouse gas emission scenarios only but also account for future land-cover changes. These improvements should especially focus on tropical areas of the developing world where population growth and deforestation are occurring at high rates.

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4

DIVERSE CLIMATE CHANGE RESPONSE IN JAPANESE ECOSYSTEMS OBSERVED THROUGH PHENOLOGY AND IMPLICATION FOR THE MEKONG REGION

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ABSTRACT

Climate change was found to have an effect on the phenological events of species and ecosystems. The relationship between climate change and phenology has been principally studied in North America and Europe; however, such studies are very limited for the Asian region. Current existing studies have not evaluated large-scale latitudinal patterns and hydrometeorological factors in the phenological responses of different species. Most studies focus on a single or several specific species' phenological characteristics. The aim of this study is to analyze the diverse phenological responses to climate change in Japanese ecosystems, and the implications for the Mekong Region. First, long term datasets of 120 different phenological events from 1953 to 2007 and hydrometeorolgical data at 55 selected sites in various regions of Japan were collected. A statistical analysis was then conducted for the collected datasets. Results showed that most species' phenological event dates were significantly affected by mean air temperature and latitude, but were not highly correlated with other factors such as longitude, altitude, air pressure, and wind. Our results showed negative relationships between the phenological response to temperature and latitude; higher temperatures tended to delay the timing of some phenology. Finally, the importance of studying vegetation phenology in other Asia region i.e. Mekong River region and the potential effect of climate change on vegetation phenology in Mekong River region has been reviewed in this paper.

Key words: Japan, Phenology, Climate Change, Seasonal Timing

INTRODUCTION

There is consensus that the Earth's climate is changing and considerable evidence has shown that climate change is having effects on many organisms and ecosystems, and that this change is projected to accelerate in the future (Schneider, et al., 2007; Parmesan and Yohe, 2003). Among these, phenological dynamics have been recognized as key attributes of plants and animals that are being affected by a warming climate (Cleland et al., 2007; Root et al., 2003; Parmesan, 2007; Parmesan and Yohe, 2003). Climate change, such as temperature rises, has already been found to affect species' phenological events and many studies have concurrently documented a progressively earlier start for vegetative activity in the spring (Walther et al. 2002, Root et al. 2003, Menzel et al. 2001). As for natural vegetation, its responses to climate change have been investigated by analyzing the observed ground data. Phenological seasons have shown signs of change, spatially and temporally, in response to trends in climate change (Menzel et al., 2001; Zheng et al., 2002). Recent changes in climate, such as increases in air temperature were found to affect plant phenological events such as earlier onset of flowering and leaf unfolding in the spring and delayed onset of leaf colouring and leaf fall in the autumn. So far, the potential impacts of climate change on natural and managed ecosystems are of concern and have been extensively evaluated by many researchers. Most published literature suggests that the timing of spring phenological events in many species is occurring earlier than in past decades (Walther et al. 2002; Gordo & Sanz 2005). However, the relationships between phenological events and climate changes have been principally studied in North America and Europe, while studies connecting phenology to climate change in Asian regions are very limited (Chen and Pan, 2002; Matsumoto et al. 2003; Doi, 2007).

The aim of this study is to analyze the diverse response of phenology to climate change in Japanese ecosystems, as well as the possible implications for Mekong Region. Long term dataset of the phenological event dates and hydrometeorolgical data at 55 selected sites in various regions of Japan from 1953 to 2007 were collected for 120 different phenological events. We will examine the relation between phenological events and hydrometeorology by compiling and analyzing the data of average air temperature, precipitation, wind, solar duration, rainfall, humidity, longitude, latitude, altitude; all the above analyses are based on phenological data collected from both literature and ground observation stations for the period 1953–2007.

Figure 4.1: Location of the selected observation sites in Japan.

Data on phenological events and hydrometeorology (average air temperature, precipitation, wind, solar duration, rainfall, humidity) from 1953 to 2007 were collected from local meteorological experiment stations, maintained by the Japan Meteorological Agency (JMA, 1985). The data for latitude, longitude, altitude for each observation site were also collected from JMA. Phenology and hydrometeorology datasets of time series longer than 20 years were selected for the trend analysis; with the longest dataset having 55 years worth of observations. 55 stations across Japan were selected according to the consistency of data collection over 20 years in order to ensure a continuous dataset across all sites (figure 4.1).

Trend analysis

Figure 4.2 shows the long term trend of phenological events in Japan. It shows a 55-year time series for all 55 selected sites in Japan. From it, we can find that the decreasing or increasing trend is obvious for some phenological events. Figure 4.3 shows the spatial demonstration of long term trends of phenological events in Japan. These two figures will be helpful for analyzing the impact of climate change on phenological process. From figure 4.2 and figure 4.3, we can choose some typical vegetation as an example to explain the time series change in detail. As an example, figure 4.4 shows the germination and leaf falling date of Morus in Japan. The germination date of morus in Japan was found to be increasing, but the leaf falling date of Japanese morus is decreasing. This result is consistent to the previously summarized typical phenological response to climate change by Penuelas and Filella (2001). The concept can be demonstrated in figure 4.5. Generally, leaf unfolding has advanced 1 to 4 weeks; leaf falling is delayed by 1 to 2 weeks; flowering is advanced by 1 week; and finally, the appearance of animals has been advanced by 1 to 2 weeks. The growing vegetation season has been extended by about 1 to 3 weeks. As summarized in figure 4.5, in recent decades, winters have become warmer, spring is starting earlier, and summer tends to become more persistent compared to previous years. Accordingly, the growing season of vegetation has been significantly extended, all of which are potentially affected by climate change.

Relation with geographical and hydrometeorological factors

For understanding the process of phenology, we collected all hydrometeorological data in selected sites across Japan. They include latitude, longitude, altitude, air pressure, rainfall, air temperature, humidity, wind speed, solar radiation for each observation site.Figure 4.6 shows the relation between latitude, temperature and DOY (day of year) for three example phonological events such as the flowering date of Camellia japonica, blooming date of Prunus, and the flowering date of Wisteria floribunda, respectively. The results show that the temperature and latitude has a strong correlation to mean flowering date of Camellia japonica, blooming date of Prunus, and the flowering date of Wisteria floribunda where as factors such as longitude, altitude, air pressure, wind, etc., show less correlation. The correlation between flowering date

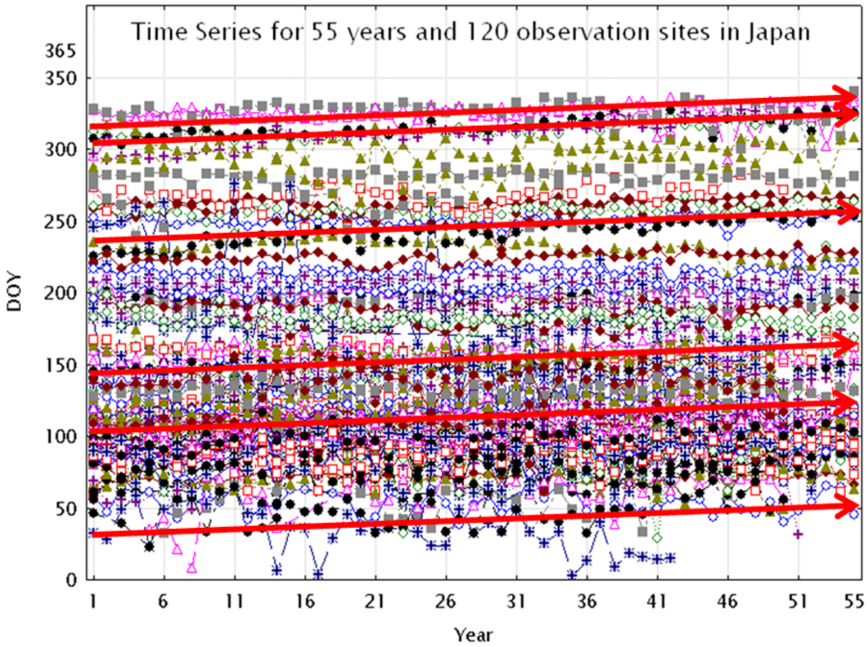

Figure 4.2: Long term trend of phenological events in Japan.

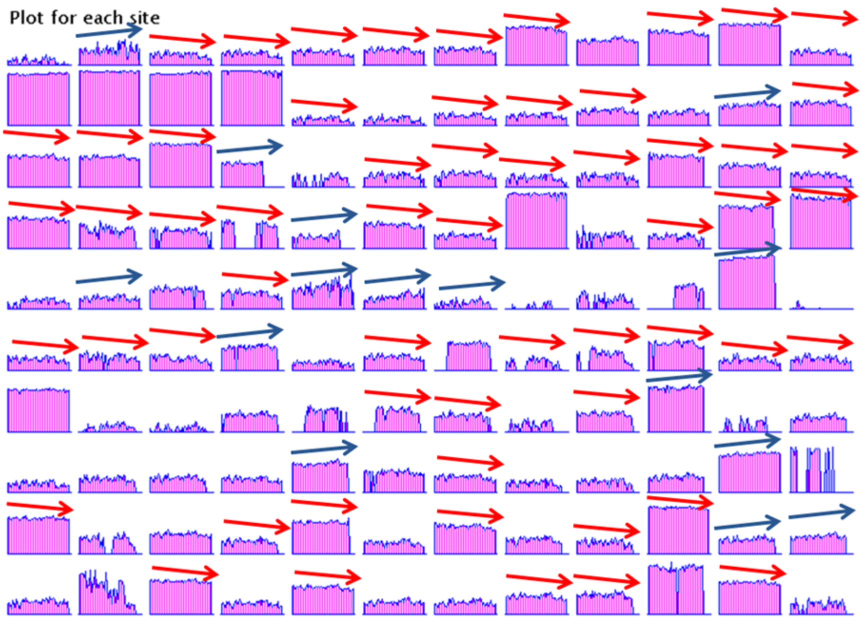

Figure 4.3: Spatial demonstration of long term trend of phenological events in Japan.

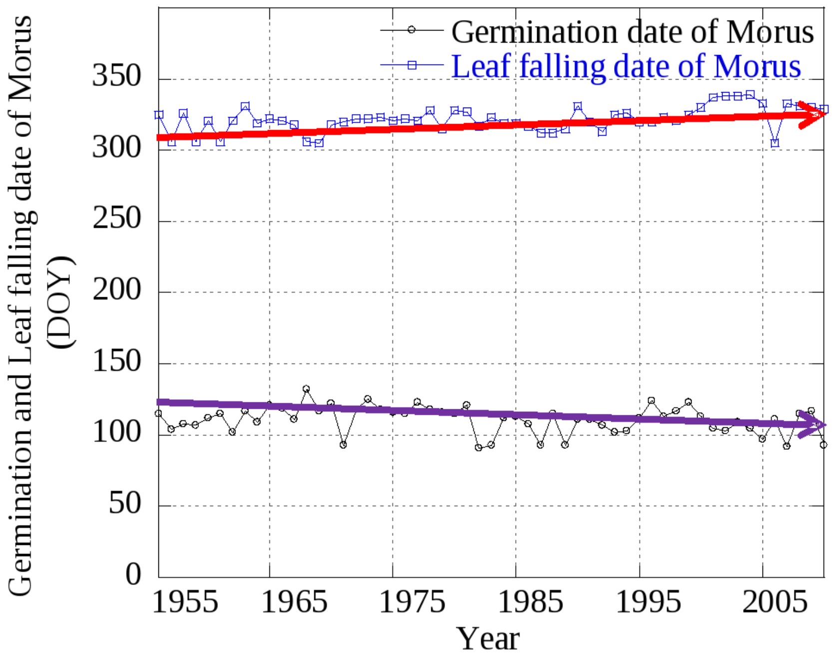

Figure 4.4: Germination and leaf falling date of Morus in Japan.

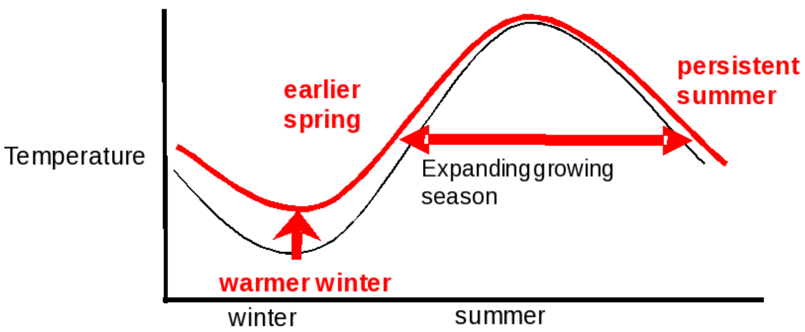

Figure 4.5: Typical phonological response to climate change (Penuelas J and Filella I 2001)

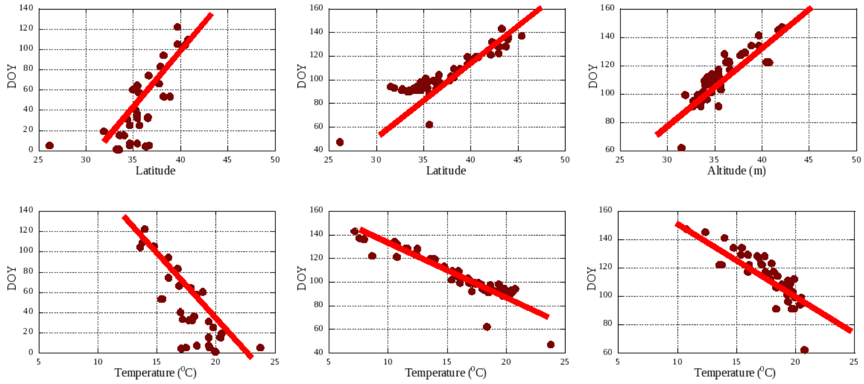

Figure 4.6: The relation between latitude, temperature and DOY for the flowering date of Camellia japonica, blooming date of Prunus, and the flowering date of Wisteria floribunda, respectively.

and mean air temperature was significantly negative, but no significant relationship was found between the flowering date with other factors such as mean air humidity, wind, etc. The relation between latitude and temperature as well as other meteorological characteristics in detail is ongoing and will be presented later.

Implication for the Mekong Region

The present study focused on the phenology of Japanese ecosystems in response to recent changes in the climate. It also contributes to the understanding of trends in phenological change in Asia more generally. In comparison to Japan, vegetation phenology in the Mekong region is more sensitive because the impacts of climate change and air pollution (for example: acid rain and ozone) on vegetation in the Mekong region. Climate change can affect physical and biological processes differently and can have different effects at different tropic levels (Inouye et al. 2000, Visser and Both, 2005). Figure 4.7 shows the spatial map of global soil sensitivity to acidic deposition, in which the Mekong River region is one of the most sensitive regions in the world. Because the phenology in Mekong region is sensitive to climate change and human activities, there are two potential issues in Mekong region. The first is the impact on agricultural production. According to the literature (Inouye et al. 2000, Visser &Both 2005), under future climate change scenarios, winter seasons will become warmer, spring crops and tropical crop varieties will become increasingly large, however growing season of crops will become shorter. The second issue is the impact on biodiversity. Climate change can cause changes in phenology,

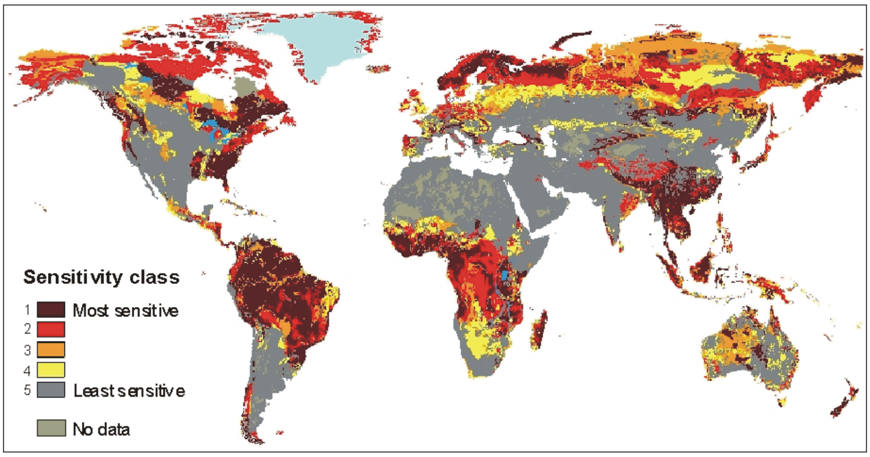

Figure 4.7: Spatial map of global soil sensitivity to acidic deposition (Kuylenstierna et al. 2001).

influencing the reproductive ability, competitive ability and interaction among species. Extreme weather and disasters would lead to a large number of species becoming directly extinct. Therefore, it is necessary to study the phonological responses to climate change in the Mekong. A comprehensive understanding of plant phenological responses to global warming will require observations that are both long-term and spatially extensive. With large data sets that span broad geographic areas and temperature gradients, scientists can improve predictions of how phenological responses and ecological relationships will change in the future. Such observed evidence of climate change can provide more accurate and valuable information for examining the mechanisms and processes of vegetation response and can also be very helpful in improving models for predicting the impacts of future climate change (Tao et al., 2006). In this case, it is necessary for us to collect more data in Mekong River basin.

DISCUSSION

Land surface phenology is highly linked with water and carbon cycles. Not surprisingly, the study of phenology and its connection with climate change is a hot topic among the scientific community today. As demonstrated in figure 4.8, which was the summary of previous research by the literature, phenology has a great impact on climate, carbon cycle and water cycle through photosynthesis and evapotranspiration. Water cycle (for example: water table due to hydrological process) will also have a great impact on ecosystem dynamics. Moni-

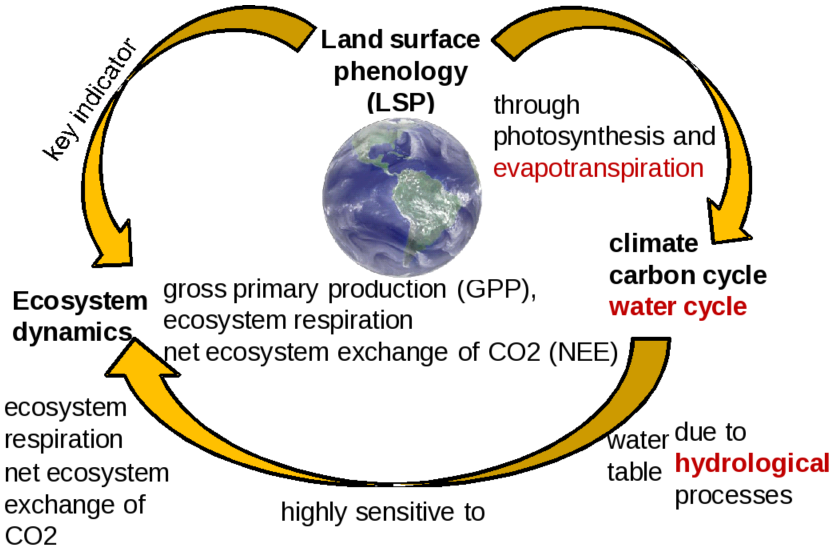

Figure 4.8: General relation between ecosystem dynamics, climate and land surface phenology.

toring seasonal changes in vegetative activity and crop phenology over wide areas is essential for many applications, such as estimation of net primary production (Kimball et al., 2004), deciding time boundary conditions for crop yield modeling (Bauman et al., 2001) and supporting decisions about water supply (Digkuhn & Gal, 1996). In this study, during the period 1953-2007, the mean flowering dates or germination dates of much vegetation in Japan were found to shift progressively earlier. Correlations show that mean air temperature had a significant effect on the flowering date, which has also been well documented by other researchers. The principal finding of this study indicates that phenological events have been gradually changing in recent decades, in response to increasing temperature. This emphasizes the necessity for developing phenological models in order to estimate the impact of climate change on plant development in the Asian region. More field studies are needed to determine how these patterns of variation in species response to climate change affect species interactions and the ability to persist in a changing climate over large spatial scales (Tao et al., 2006).

CONCLUSIONS

The present findings in this study indicate that the timing of phenological events has advanced as a result of recent changes in the climate. We found negative relationships between leaf phonological responsiveness and latitude. These findings will be important for predicting phenological timing under global climate change, as well as fully estimating the response of vegetative life cycle to temperature increases. The results from the present study underline the need to collect more ground observed dataset and estimate the reactions of vegetations to climate change in Asia.

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5

CLIMATE CHANGE IMPACTS ON BIODIVERSITY CHARACTERISTICS IN LANCHANG- MEKONG BASIN

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BIODIVERSITY CHARACTERISTICS OF MEKONG BASIN IN CHINA

The Mekong River is the longest river in Southeast Asia and the 12th longest in the world. Its source is located at the north-eastern rim of the Tibetan plateau (Qinghai Province) at an elevation of more than 5000 m. from there it flows through six countries: People's Republic of China, Myanmar, the Lao PDR, Thailand, Cambodia and the southern end of Viet Nam before it reaches the South China Sea, where it discharges on average, 475 000 million m^3 per year (15 062 m^3 per second). The river has its source on the northeast rim of the Tibetan Plateau and flows for approximately 4,880 km to the South China Sea through the Mekong Delta in Viet Nam. The Mekong River Basin covers a total land area of 795,000 km^2, making it the 21st largest river basin in the world.

The upper part of the river is called Lancang Jiang (in China), it is 2 400 km long and is characterized by deep gorges and steep declines. Having fallen to about 360 m, it passes the Golden Triangle, where the borders of Lao PDR, Myanmar and Thailand meet. The river has also served as a symbolic bond of kinship and friendship for the various ethnic and population groups living within the watershed. Furthermore, the riverine system is rich in flora and fauna, many of which are endemic to this particular and unique ecosystem. The unique geomorphology of the Mekong River Basin during uplifts of the Qinghai-Tibet Plateau has had a great influence on water and temperature distribution in the region. High mountain ridges are punctuated by steep river valleys (developed along the north-south way) which lead to the complex circulation of moisture and atmosphere, unique biodiversity distribution along corridors and barriers, and other ecological effects, which drive a bulk of the ecosystem formation and change in the region.

The variety of latitudinal and altitudinal zones has resulted in various types of climate resources and in the intact vegetation vertical zones of tropical and subtropical characteristics. The area is rich in relic species, which are species that have originated from quaternary glaciations. Rich diversity in species and regional species endemism is also an obvious biological feature of the area: including millions of species from tropical to the alpine Snow Belt, including tropical rainforest, subtropical ever-green broad-leaved forest, mountain needle-leaved forest and dry-hot valley ecosystems, alpine meadow, alpine grassland, wetland ecosystem. Plant floristic is complex, with the number of plant species reaching up to 10,000. There are approximately 2000 fish species, 700 bird species, and more than 210 mammal species. Since 1958 some universities and research institutes have conducted a survey of fish resources and collected fish specimens in different reaches along the River. One hundred thirty seven endemic fish species from the Lancangjiang River have been recorded; additionally, there are 15 introduced species in the river drainage. Some species are listed as international endangered species such as the Snow leopard, Golden Monkey, Gibbon, Elephant, Peacock. Tiger. This area is a hotspot of biodiversity in the world.

BIODIVERSITY PRIORITY CONSERVATION RESEARCH IN THE MEKONG RIVER BASIN

Hotspot analysis for species conservation in China

According to the following criteria, we selected 89 mammal, 169 bird and 345 plant species with specific characteristics based on the endangered and endemic criteria as the indicator species in the analysis. We selected species endemic to China whose status is considered endangered or threatened; species whose population are mostly located in China and are endangered or threatened; species that are endangered domestically. We then established a database for selected species which includes population size, habitat, biology and ecology, threats, conservation status and range map. Some datasets are based on the national wildlife survey.

Selection of hotspot areas is based on areas with a high number of indicator species distributions in one location and where natural vegetation is maintained with negligible human impact. From a regional perspective, the hot spot unit forms a relatively independent catchment area or mountain range. According to this criteria, 26 hotspot areas are identified: Changbai Mountain area, Qilian Mountain area, Funiu Mountain area, Qingling area, Daba Mountain area, Dabie Mountain area, low hills in Zhejiang and Anhui, mountainous areas in Zhejiang and Fujian, high mountain and valley areas of west Sichuan, southern area of east Tibet, northwestern part of Yunnan, Wuling Mountain area, Nanling Area, Shiwandashan Mountain area, Xishuangbanna area, and central Hainan.

Two priority areas in Mekong River Basin were identified for hotspot analysis for species conservation: Northwestern part of Yunnan and Xishuangbanna area.

Integrated biodiversity conservation priority studies

Systematic conservation planning is based on clear, quantified conservation targets, and uses an irreplacebility index for each planning unit in setting priority areas of biodiversity conservation. Using digitized 1:1 million vegetation map, we mapped potential habitats of 216 focal species: 59 mammal species, 51 bird species, 106 plant species. Focal species were selected based on IUCN list, CITES lists and China National Key Protection Species lists. The whole ecosystem includes totally 683 natural ecosystem types, 145 priority ecosystem types, which were identified based on the criteria as: Dominant ecosystem in the ecoregion, Zonal ecosystem, Endemic to China.

The calculation of irreplaceability values are discussed in Pressey et al (1994) and Ferrier et al (2000). Irreplaceability of each planning unit was calculated by using CPLAN based on the targets of priority ecosystems and focal species.

Criteria for identifying priority areas used in this study are: concentration of the grids with higher irreplaceablilty; concentration of well-conserved natural vegetation; entirety of biogeography unit. In total, 26 priority areas were identified.

Key biodiversity area in MKRB in China

Sanjianyuan area

Three major rivers arise from Qinghai – the Yellow River, Yangtze, and Mekong (called Lancang in China). Sanjianyuan's global biodiversity significance arises from its high ecosystem diversity – forest ecosystems, rangelands, wetlands, deserts and agricultural lands. This lake along with Zhaling Lake and Eling Lake are recognized for their global

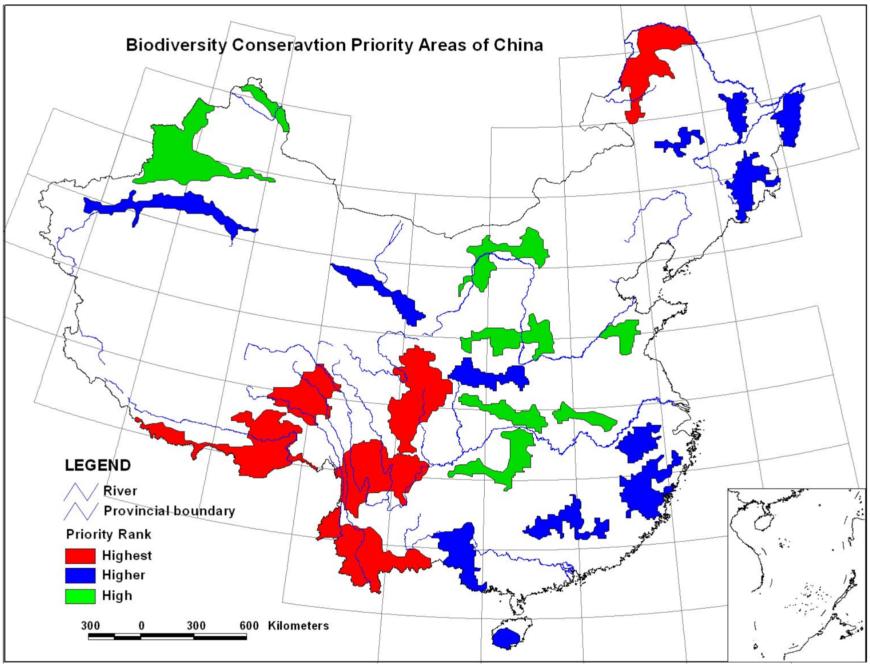

Figure 5.1: Biodiversity conservation priority areas of China

importance and is listed as Ramar Sites. These are key habitats for migratory birds, and large populations of Black Crane, Grus grus, Cygnus cunus, Larus brunnicephalus, Sterna hirundo tibetana are found here. Significant populations of globally threatened species such as the wild yak, wild ass, Tibetan antelope, Cervus albirostris, and snow leopard are also found in the area. In fact, the area harbors more than 7% of higher plant and vertebrate species recorded in China – with a total of 2380 higher plant species and about 400 vertebrate species. There is a high level of endemism in the area: more than 50% of plant species found here are endemic to China. Among them, more than 30 species are listed as national key protection species. 21 higher plant species found in the Province are also listed in the national list of key protected species and more than 40 plant species are listed in the CITES Appendices.

Northwest Area of Yunnan

This region includes the westernmost part of the rugged mountainous area, the steep valleys of the Hengduan Range in northwest Yunnan, and covers more than 20 counties and city administrative units such as Lushui and Fugong. The deeply incised Nujiang River valley separates the western Gaoligong Mountains from the Biluo Snow Mountains to the east. The region is the meeting place of the Palearctic and Paleotropical plant kingdoms and is one of the most concentrated sources of plant type specimens in China. The fauna belongs to a transitional zone of the India-Burma system and central and south China systems. There are more than 100 species of mammals and nearly 300 species of birds that have been thus far identified. The region has been variously identified as the "center of mammal species differentiation", the "pheasant paradise of the world", the "north-south corridor for wildlife movements" and the "Quaternary refugia for primitive mammals". Many endemic species such as Yunnan Snub-nosed Monkey (Rhinopithecus bieti), Red Panda (Ailurus fulgens) and Black Musk Deer (Moschus fuscus) are distributed in this region.

Xishuangbanna Area

Located in the southern part of Yunnan Province, Xishuangbanna is bounded by the international boundaries of Myanmar and Laos and the northern edge of tropical Asia with a total area of some 3.28 million ha. Monsoon rain forest grows in these areas which have the elevation of less than 800 m. The biodiversity of this region is characterized by high species richness. Although the area accounts for only 0.2% of China's territory, the number of higher plant species exceeds 4,000, about 7% of the country's total. Wildlife is abundant and accounts for many protected species with 102 mammals, some 25% of all mammals were found in China. Most are arboreal or tropical forest species, including many of the primates and civets that are found in China. Bird species thus far identified, number 427, as well as 38 amphibians, 60 reptiles and 100 fish species. Despite this incredible species richness, there are a comparatively low number of endemics.

BIODIVERSITY THREATS AND CONSERVATION EFFORTS IN MKRB IN CHINA

Biodiversity threats in MKRB

The Lancangjiang River (the upper Mekong) basin is an important area in biodiversity and is a rapidly developing area. The devastating effects of human activities and global climate change have caused extremely serious land degradation in MKRB, such as vast soil erosion, serious desertification and shrinking wetlands, increase in degraded pastureland, and deterioration of wild life habitat, all of which have led to biodiversity loss. The following are some examples of typical direct threats:

Over-grazing: The grassland ecosystem used to be traditional grazing lands for local communities. Overgrazing is the key factor for grassland degradation. During springtime, livestock form outside the NR grazes inside the NR, seriously damaging the grasslands and increasing the exposure to surface soil erosion and consequently, degradation of grasslands and lowering of the quality of livestock products. In some cases, villagers cut down the trees or clear the scrub lands on the edge of forests to enlarge grazing lands. This has brought about some conflict between grazing lands and forests.

Encroachment of Farmland: Most communities lie in high elevation mountain areas with poor production value. Because of poor farming methods and lack of fertilizer, the crop yields are very low. Most households lack food for 4-6 months. As population increases and there are no other means of income, the usual practice is to clear forest for more farmland, bringing about further conflicts between farmlands and the protection of forests.

Illegal timber and fuel wood collection: High consumption of timber for house building in Yunnan and Tibet area is popular. The major energy for local communities is fire wood, which is a major threat for the protection of forest.

Dam and road construction also lead to fragmented wildlife habitat and ecosystem services, this is a particularly big issue for fish conservation.

The MKRB is located in an under-developed area, where birth rates are higher than the average of China. This leads to high pressures on the resource base and on biodiversity. Population growth continues to be a source of threat to biodiversity. The Government sets high production targets which add great pressure on the biodiversity, as the production may not be compatible with local sustainability. In this basin, the growth is still very dependent on the natural resource base, and will be continued for some time, so that it is difficult to achieve growth without unsustainably exploiting resources. Poverty is considered a fundamental driver of biodiversity loss. For poor people, survival is the only issue. It is noted that, in China, biodiversity rich areas correlate strongly with the high-poverty areas. The scale of energy use, the source of energy, the shortages of energy, efficiency in use, and the moves towards renewable energies are all major issues for biodiversity. The biggest impacts on biodiversity are through the use of wood as a fuel and the use of hydro-electricity from dams. The impact of using wood as fuel is generally negative, but new technologies may lead to an increased value of wood as a fuel, and encourage a sustainable harvest. It is noted that the use of wood for fuel is very small in terms of regional statistics, but it does have an important impact on biodiversity. Transportation sector development can have negative impacts on biodiversity, through: habitat fragmentation and habitat loss. Transport can also facilitate the arrival and spread of invasive species, notably through ballast waters. The agriculture sector has also contributed to over-grazing, pollution, and land conversion.

Climate change is a new challenge for biodiversity conservation. As Qinghai lies in a high altitude area, climate change impacts are already being felt in the region, with an overall average increase of 1.5 degrees Celsius from 1961 to 2006 and reductions in ice volumes of glaciers. In fact, some smaller wetlands have completely dried and there has been a significant reduction in volumes of runoff in rivers. There has also been an increase in the frequency and intensity of extreme climate events such as droughts, high intensity rainfall days and hailstorms. Due to lack of information and understanding on climate change impacts on biodiversity, relevant adaptation strategies have not been developed and this issue has been ignored in ongoing conservation activities.

Conservation efforts

Central and local governments have recognized the seriousness of ecosystem degradation and biodiversity loss in the region. The State Council approved the Master Plan for Ecological Conservation and Construction of the Sanjiangyuan National Nature Reserve in Qinghai in January 2005. The upper reach of the Mekong River is also included in the project area. The project aims to promote sustainable development of the environment, economy and society in the Sanjiangyuan region by 2020.

In Xizang and Yunnan, many national nature reserves have been established, such as Mengkan NNR in Xizang, Baimaxueshan, Wuliangshan, Nangunhe, Cangshan-Erhai, Xishuangbanna, Bannahe in Yunnan. 19 nature reserves were established in Yunnan, totaling 855,400ha in size, and occupying 9.6% of the total area in Yunan Province.

Many new ecological protection strategies and projects have been issued, such as the nature forest protection program, grain for green (return steep agriculture land to forest land), and forest eco-service compensation strategy to change logging farm into forest management. All of which have had a great impact on forest ecosystem sustentation.

Some suggestions for MKRB biodiversity conservation and ecosystem service sustention

Conduct biodiversity surveys and inventories for MKRB

Although many nature reserves have been established, biodiversity inventorying has just partly been conducted. Monitoring biodiversity in this area and conducting special interventions to avert extinction is an urgent action for this area of scientific conservation. Based on the production of systematic inventories of biodiversity, including the synthesis of existing data, we can develop indices of biotic integrity and monitoring programmes to detect environmental change and/or deterioration, and implement management measures to habitats and species assemblages.

Special concern was voiced about projects impacting the entire mainstream of the Lancang -Mekong River. We need to develop nationwide and basin wide policies for the management of alien/exotic species to protect native biodiversity and use of flagship species to promote biodiversity and sustainable development. New techniques should also be developed to integrate all available relevant information (e.g., climate, biodiversity, population and economics) about the Lancang-Mekong River Basin into a package that is easy to understand and which allows for the modeling of different development options.

Create transboundary Protected Area to conserve large-scale migration corridors in freshwater and terrestrial ecosystems

Migratory animals are "living threads that tie or link widely scattered ecosystems together". The management of such animals requires management of all the essential habitats upon which they depend, including the migration pathways between the habitats. It does not, for instance, make sense to establish "protected areas", or any other management measure, for an important fish feeding area, if at the same time their spawning habitats are being destroyed. Many migratory stocks extend beyond national borders (often referred to as "trans-boundary" stocks) and thus require intergovernmental co-ordination in research and management. A transboundary protected area is an area of land beyond the limit of national sovereignty or jurisdiction, whose constituent parts are especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed co-operatively through legal or other effective means.

In the border area, we need to establish one transboundary protected area for freshwater and fish conservation along the Mekong River, as well as for the conservation of terrestrial migratory large mammals such as elephants and tigers.

Reduce threatening processes at the landscape scale for species and ecosystem services

Adjustment of Environmental Impact Assessment (EIA) policies and practices to ensure that biodiversity is given due weight in EIA reports. Biodiversity (and especially transboundary biodiversity) issues must be placed at the core of the decision-making process in the large construction projects in the Mekong River basin. We also need to conduct impact assessments to identify and protect climate refugia and improve the Protected Areas system and management effectiveness in MKRB.

Conserve natural processes and connectivity at the landscape scale

Connectivity conservation focuses on maintenance and restoration of ecosystem integrity across entire landscapes in the basin conservation. Connectivity is built around core habitats or refugia protected in reserves which are linked and buffered across different tenures and land uses in ways that maintain natural ecosystem processes. Connectivity conservation is a proactive, holistic, and long term approach which is achieved by agreements, incentive schemes, land-use planning, philanthropic actions, business transactions or other appropriate actions.

The challenges for connectivity conservation are to: identify and enhance desired flows particularly for keystone, endangered and vulnerable species; monitor and hinder threatening processes such as feral pests and weeds; and coordinate these actions across tenures and land management regimes both on and off the reserve system. It is necessary to prevent land clearing, water diversion and intensification of uses in remaining natural areas in order to preserve options for a comprehensive climate adaptation response.

Enhancement of communication and networking among regional stakeholders to be able to contribute to biodiversity research and conservation

We should strengthen international, transboundary linkages and initiatives, as well as establish a formal network of researchers to discuss issues relevant to the Lancang-Mekong River Basin and strengthen local capacity for undertaking biodiversity research, including increased funding and support for researchers, students, equipment, infrastructure and joint international workshops. Moreover, we should identify, designate and establish additional protected areas within the Lancang-Mekong River Basin for the benefit of biodiversity and humans.

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6

LAND USE CHANGE, CAUSE AND CONSEQUENCE IN MONTANE MAINLAND SOUTHEAST ASIA: A CASE STUDY IN NORTHERN LAOS

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ABSTRACT

The Montane mainland Southeast Asia (MMSEA) plays multiple ecological and cultural functions. Natural resource management is now subject to increasing interventions of policies promoted by central governments and international agencies. As a major traditional land use in MMSEA, shifting cultivation was often perceived as a "primitive" land use system associated with low productivity, poverty and deforestation. As a result, various land use policies have been implemented to discourage shifting cultivation and to promote "advanced" sedentary cultivation in MMSEA. This case study was carried out in Northern Laos to investigate, the sequence of policy interventions and their contribution to the transition of traditional shifting cultivation and the consequences of the transition since 1970's. A number of policy interventions has restricted land use, especially land availability for shifting cultivation. Without change in the agricultural technology, the resulting intensification of land use has led to land degradation. In response, local farmers adapt to this problem by the adoption of tree plantations and expansion of off-farm opportunities in urban centers nearby. If teak plantation is considered as a kind of sedentary agriculture, then past policy interventions for promoting sedentary agriculture in upland Laos has partially realized its objective, but with mixed impacts on ecology, economy and society. Further assessment is needed to understand the trend and drivers of land use transition, the role of policy interventions and adaptive capacity of farmers in response to policy interventions in the region.

INTRODUCTION

Mountains occupy about one fifth of the terrestrial surface, are home to 20% of the world's human population and provide humankind with multi-functional resources and services. Mountains serve as "water towers" to half of humankind in one way or the other. Mountains harbor high biological and ethno-cultural diversity. However, mountains are fragile ecosystems. Internal and external pressures driving land use systems towards unsustainable put the integrity of the fragile mountain ecosystems at risk in many parts of the world. Environmental conservation and sustainable land use systems in the mountains are not only a necessary condition for sustainable local livelihoods, but also a key to human well-being for nearly half the world's population who live downstream and depend on mountain resources.

The Montane mainland Southeast Asia (MMSEA) encompasses the Yunnan Province of China, the Kachin and Shan States of Myanmar and the northern region of Thailand, Laos and Vietnam, extending to Northeastern India and home to some of Asia's poorest and most disadvantaged people, many of whom represent a diversity of ethnic minority groups. MMSEA serves as watersheds for a few large rivers in the sub-region, including the Brahmaputra, the Irrawaddy, the Mekong, the Salween, the Red River, the Pearl and the Yangtze. MMSEA harbors a diversity of endangered and endemic species of global significance.

Land use change, especially deforestation in MMSEA, is a major cause of environmental degradation with negative impacts on local livelihoods as well as biodiversity and watershed services. Deforestation undermines capacity of rural communities to live with hazards-prone mountain environments, degrade habitats for wild life, increase risk of soil erosion and lose carbon sinks. The main driving force of deforestation is the unsustainable transition from traditional agriculture to commercial agriculture driven by internal and external factors, such as population growth, policy and social-economic changes. One of the major traditional mountain agriculture land use systems is shifting cultivation, which used to be widely practiced in MMSEA. Traditional shifting cultivation integrates a brief phase of cropping for food production and a long phase of forest fallow for regeneration of soil and forest products. During the cropping phase, the field preparation and management will ensure not only food production but also forest regeneration to restore soil fertility lost during the cropping phase. Where it is possible, local peoples develop permanent valley or terrace fields for wet-rice cultivation, home garden, animal husbandry and farm forestry to diversify dependence of livelihood security from shifting cultivation.

Shifting cultivation was often perceived as a "primitive" land use system associated with low productivity, poverty and deforestation. As a result, various land use policies have been implemented to discourage the shifting cultivation and to promote "advanced" sedentary cultivation in MMSEA. However, there is limited understanding of how the past policies have contributed to transition of traditional shifting cultivation towards sustainable land and forest management. This knowledge gap has been addressed through a comparative study and exchange across different ethnic cultures and countries in MMSEA by a regional research network on sustainable land management in MMSEA (SLM-MMSEA), which has been developed by United Nations University (UNU) in cooperation with Kyoto University, Japan and national partners of the region since 2005. Under the partnership, 9 comparative study sites have been identified; 2 in Northeast India, 2 in Northern Thailand, 3 in Laos and 2 in Yunnan, China(figure 6.1).

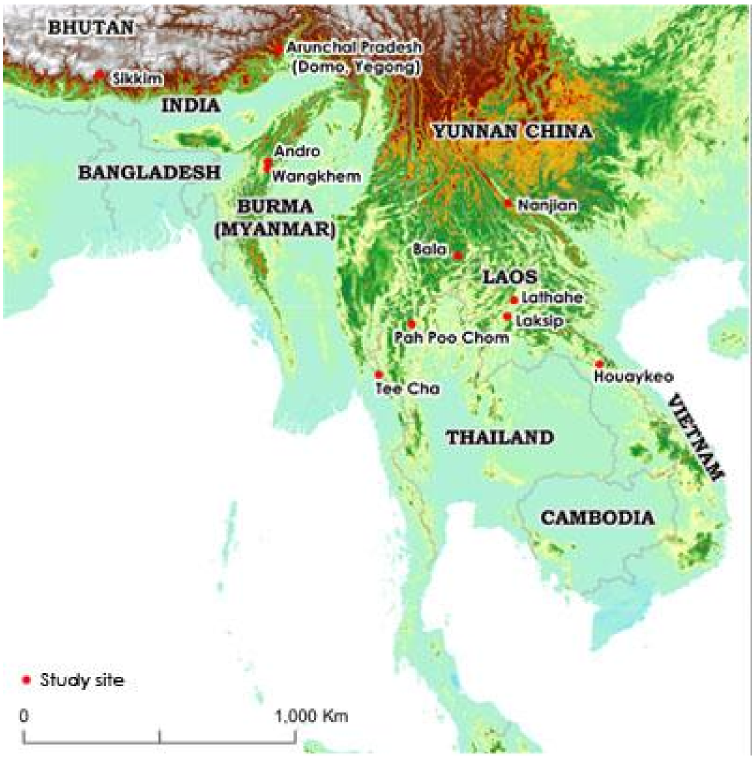

Figure 6.1: Study sites in MMSEA

Upland areas of Laos are an important part of the watershed of the Mekong. Over last few decades, several policy interventions have been implemented to stabilize shifting cultivation practices in the upland areas. UNU and National Agriculture and Forestry Research Institute (NAFRI) in Laos have initiated a case study in the country to evaluate to what extent and how land use policies and interventions have contributed to development of alternative land use in upland Laos.

RESEARCH METHODOLOGY

The case study was planned as part of the SLM-MMSEA research program. An expert group of the SLM-MMSEA met and identified the priority research question for the case study. Specifically, the case study aims to investigate the traditional land use system, the sequence of changes in the policy related to land use management over the past few decade and examine the present land use pattern and implications for sustainable land management. In response to the research question, the quasi-experimental design was adopted to compare situations differing in the presence or absence of policy interventions. That is to say, historical comparison of what was before the policy interventions and what is after the policy interventions at the study site will be carried out. The research team selected Ban Laksip in Northern Laos as the study site where a number of policy interventions have been implemented over past few decades and the traditional shifting cultivation is under rapid transition. Selection of Laksip village is also based on availability of the previous research data. The Houay Pano catchment with an area of 60 ha in the Ban Laksip is a benchmark site for the project on Managing Soil Erosion Consortium (MSEC) to assess the impact of rapid land use change on the environment and crop yields. The project was initially supported by IBSRAM (International Board for Soil Research and Management) and the ADB and is currently funded by IWMI and IRD. MSEC forms an important source of information for the proposed study (Lestrelin, et al, 2007).

The research methods integrate "Birds' eye view" such as land unit transect, systematic understanding, macro-scoping, GIS mapping, and "Worm's eye view," such as farmer's understanding/classification of land unit and utilization, micro-scoping, participatory rural appraisal. The schedule of the research work and exchange was as follows:

- May-June 2008: preparation and organization of the inception meeting in Luang Prabang
- July-October 2008: Compilation of secondary data and review (sequences of policy interventions and development activities and

relevant maps from all sources); Census survey on biophysical and social economy; customization of field methodology for land management survey

- November-December 2008: preparation and organization of the regional workshop and the training of trainers on the field methodology in Luang Prabang
- January-April 2009: Land use survey, land ownership survey, historical events, relocation of Huaynokpit, May 2009: evaluation and planning meeting in Luang Prabang
- May-October 2009: survey of land management and its transition through both group interview and sampling survey, and drafting village monograph, and analysis on extent and driving force of land use change
- November 2009: presentation of the preliminary findings at the regional workshop in India
- December 2009: Study visit to Xishuangbanna (China) on the impact of cash cropping: the case of rubber plantation
- January 2010: Analysis on consequences of land use change and Drafting project reports
- February 2010: Synthesis of project findings and presenting the findings to local officials and village committee at Ban Laksip village and researchers at NAFRI, Vientiane
- March 2010: Reporting

THE STUDY SITE: BAN LAKSIP, NORTHERN LAOS

Ban Laksip is an upland village, located at a latitude between 102° 08′ 38″ and 102° 11′ 33″ E and longitude between 19° 47′ 42″ and 19° 52′ 00″ N. The village is 10 kilometers away from the Luang Prabang City along the national road No. 13 which links the northern Laos to Vientiane. The topography of the village area is mountainous and the elevation largely from 400 to 600 m. The village is part of the watershed divide between the tributary streams directly to the Mekong and those flowing into the Nam Khan River which later enters the Mekong at the Luang Prabang city. This area has a tropical monsoon climate with the hot wet season from April to October and the cool dry season from November to March.

The village is under the jurisdiction of the Luang Prabang District of the Luang Prabang Province. Total population of the village is 450. There are 90 families in the village. 80 families are Khmu, 9 families Laoloum and 1 family Hmong. The village livelihoods are varied, including production of upland rice, maize, Job's tear, and vegetables, plantation of teak, husbandry of livestock, collection of NTFPs, off-farm laboring and trading. The agricultural land is concentrated in the valley of the Houay Xon stream. The village settlement is also located along the stream.

Historically, the village was founded by three families in 1962. The village population increased slowly between 1962 and 1975 with the arrival of new families fleeing the war in the northern provinces of Laos. Then, as part of the national resettlement scheme, the village underwent three important immigration waves as follows:

- 1976-77: 9 families from Huaytong village, located less than 0.5 km away, joined with Ban Laksip,
- 1982-83: 12 families of Naxone village, located less than one kilometer, joined with Ban Laksip,
- 1996-97: 24 families from Houaynokpit village about 3 km away in the south joined with Ban Laksip.

The total land area of the village was 433 hectares, as delimited by government authorities in 1975. In 1997, after Huaynokpit was merged with Lasip, the village land area was expanded to cover the whole Huaynokpit, based on the agreement of the district committee dated 27 April 1999. Currently, the total land area of Laksip is 1746 ha, consisting of three main land use types: forest land, production/agriculture land and residential land.

Sequence of policy interventions

A number of major policy interventions have been implemented in the Laksip village since 1975. The National Resettlement Programme aimed to improve access to infrastructure and public health through relocation of small and remote villages to the more accessible and larger village. As a result, two small villages, Huyatong and Nasone, merged with Laksip in 1976 and in 1982, respectively. Both villages were close to Laksip. The relocation affected residence, but did not change the land ownership pattern in both their original villages as well as Laksip. The families from these two abolished villages continued management of their original lands. As a result, the relocation itself did not increase population pressure on land resources in Laksip village.

From 1985 to 1991, FAO implemented a project to assist the local government in the management of natural resources and promoting alternative land use options to replace shifting cultivation in three watershed areas: Nam son watershed (including Laksip village), Nam Xi watershed and Nam Khan watershed. The project established nurseries for production of tree seedlings, especially teak and demonstrated sustainable land management practices (terracing, agroforestry, hillside ditch, alley cropping and chicken raising). Terracing for paddy fields was the main activity of the project. It consumed too much of labors to replicate it at family levels. Crop yields were very low in the first few years since the removal of top soil for making dikes led to low soil fertility. Raising yellow chicken could not be continued since the chicken were not adapted to the local situation and became sick. Nurseries of tree seedlings, especially teak seedlings were successful. Farmers learned from the project and expanded teak plantations by themselves after the project finished.

Land use planning and land allocation programme (LUPLA) was a major policy to promote sedentary production to replace shifting cultivation through allocation of secure land titles to individual family and organizations on potential capacity in terms of labor force and capital for the development of the land, and to protect forests through land use zoning. With secure land titles, villagers would be expected to increase long-term investment on improving land productivity for sedentary cultivation system and in turn reduce pressure on the existing forests as well as support forest rehabilitation. The original procedure of the LUPLA had 8 steps as follows:

Step1: Preparation

Step2: Village Boundary Survey, Land Use Zoning, Forest Surveys and Land Use Mapping

Step3: Data Collection and Analysis

Step4: Village Land Use Planning and Allocation Meeting

Step5: Agricultural Field Measurements

Step6: Preparation of Forest and Agriculture Agreements

Step7: Land Use Management Extension

Step8: Monitoring and Evaluation

The above procedure of LUPLA has been modified based on experience accumulated since its beginning in 1990-91. LUPLA was implemented at the village in 1995. The village boundary was demarcated and zoning of agriculture and forest lands was delineated through LUPLA. Allocation of land to individual household is based on the customary arrangement.

This program brought out an agreement between village authorities, organized in a committee for the occasion, and the national authority represented by District Agriculture and Forestry Officers and other district financial and planning officers. The agreement that was reached determined the boundaries of forest land and agriculture land. As a result of zoning, forest areas covered 281 hectares (accounting 65% of village land), agriculture land set at 136 ha (31% of the village land) and the remaining 16 hectares were set as residential area.

The process of land allocation was based on existing customary rights and consisted of 3 steps:

- 1st step: registration of land, including number of parcels and their locations, owned by each family.
- 2nd step: measurement of the land parcel area, which is assessed by the seed amount for the land area. For example, 50kg of rice seed is roughly equivalent to 1 hectare of land area.
- 3rd step: allocation of land in which the family with more land should give some to the family with the smallest area of land, depending on family members available.

LUPLA classified 65% of the village land as forest land and significantly reduced the land availability for agriculture. Farmers are no longer able to continue the traditional practice of the long-fallow shifting cultivation. Farmers need to develop alternative land use systems or off-farm livelihoods.

Watershed conservation policy was implemented in 1996 to protect headwater areas of Luang Prabang District to the northwest of the village and Xienngeun District to the southeast of the village (figure 6.2). The former Huaynokpit village was located in the headwater areas and was relocated to Laksip. Relocation was based on their choice. Some villagers moved to Densavanh village where more land was available, but most chose Laksip with good access to road and Luang Prabang. The agreement of the district committee dated 27 April 1999 decided the merger of Huaynokpit with Laksip. As a result, the Laksip village land was extended to cover the whole land of Huaynokpit, but this additional land area is classified as protected forest land. Currently

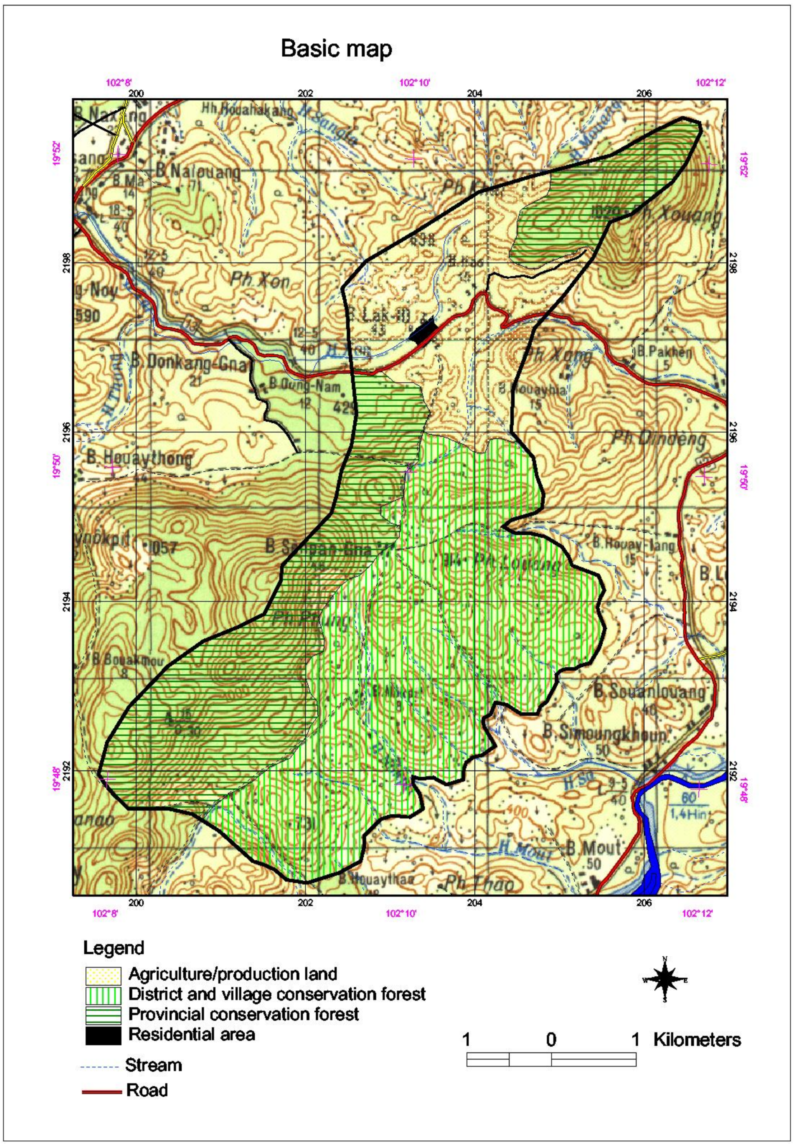

Figure 6.2: Boundary and Land Use Zoning of the Laksip Village in the Topographic Map

	1970s	Present
Annual Crops	One crop, rice mainly	Three crops (rice, maize, job's tear) intercropped with teak
Fallow period	> 5 years	2 years
Tools	Machete and planting stick	Machete, hoe, planting stick
Tillage	No-tillage	Some tillage with hoe
Farming system	Rice-based shifting cultivation	Cash crops-based short fallow, teak plantation, vegetable garden

Table 6.1: Changes in Land Use and Management

total land area of Laksip is 1746 ha consisting of three main land use types: Forest land of 1100 ha, covering 60% of total land, agriculture land of 547 ha, covering 31% of total land. The remaining land areas of 99 ha, covering 9% of total land, are for residential and other uses.

The implementation of the policy increased both population and land of Laksip, but it did not result in higher population pressures on the existing agriculture land since additional agricultural land was allocated to Laksip from neighboring villages to accommodate immigrants from Huaynokpit.

extent of land use change

Rapid land use change has taken place since 1970's, when the traditional land use system was mainly the subsistence-based shifting cultivation. Generally, one crop, mainly upland rice was cultivated after clearing. There was no use of hoe to till the field. Then, the field was fallowed for more than 5 years. Currently, the land use system has become largely commercial. Three crops are cultivated. The most common practice is the rotational intercropping of upland rice with teak seedlings in the first year, maize with teak in the second year, job's tear with teak in the third year. The plot is left to be teak plantation from the fourth year. While rice is for home subsistence, other maize, job's tear and teak are cultivated mainly for commercial purpose. During the three year cultivation, hoe is used to till the fields for excessive weeds. In case the fields are to be used for rice cultivation again for the next cycle, the fields are not intercropped with teak and will be fallowed for about two years only. These changes are summarized in table 6.1.

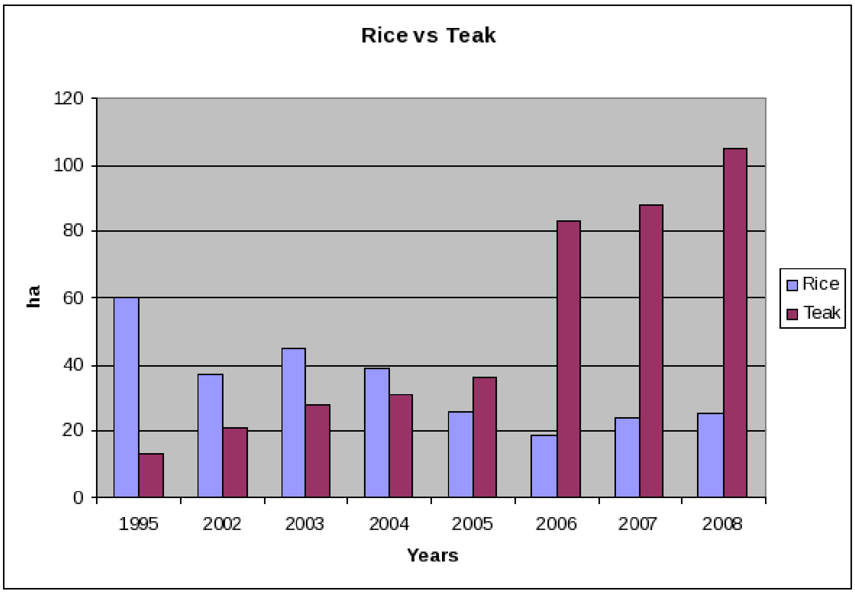

Figure 6.3: Changing upland rice to teak at village level (1995-2008)

The common practice of intercropping of annual crops with teak has led to gradual expansion of teak plantation from less than 20 ha in 1995 to more than 100 ha in 2008. The expansion of teak plantation has reduced availability of fallow lands for rice production. The rice area has reduced from 60 ha in 1995 to below 30 ha in 2008 (figure 6.3 and 6.4).

While the fallow period of the shifting cultivation continues to decrease from more than 8 years in mid 1970's to about 2 years in 2009, the cropping period continues to increase from one crop in mid 1970's to two crops in 2009 (figure 6.5).

Another major land use change is rapid development of vegetable gardens for cash income, including parsleys, ginger, chili, beans, lettuces, watercress, etc based on a continuous cultivation system. Parsleys used to be collected in the natural forests, now are widely cultivated by farmers for the market in Luang Prabang (figure 6.6).

DRIVERS OF LAND USE CHANGE

Land use change in Laksip is caused by both policy interventions as well as social-economic change. The Relocation Policy in 1976-82 relocated Huaytong and Nasone to Laksip with better access to public service and market and facilitated development of commercial production as well as off-farm jobs. The FAO project introduced teak nursery

Figure 6.4: Rice Cultivation Followed by Teak Plantation

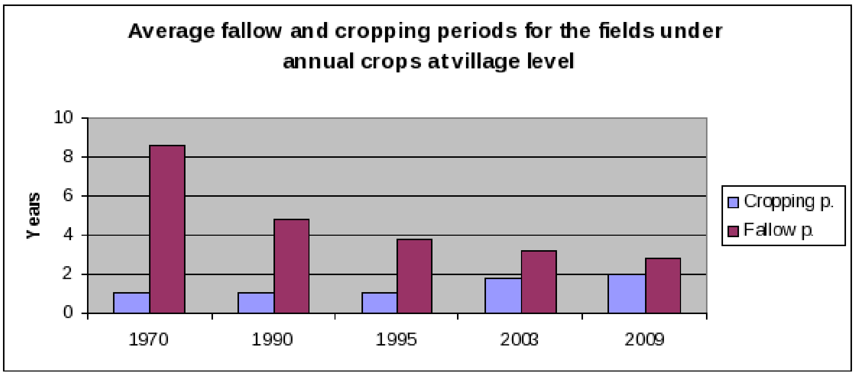

Figure 6.5: Average Fallow and Cropping Periods of Shifting Cultivation from 1975 to 2009

Figure 6.6: Parsley Garden

technique and supported villagers to expand the teak plantation. LUPLA, especially land use zoning in 1995 delineated between forest and agricultural lands. Most forests were closed from timber production and cultivation. As a result, cultivation has to be intensified on reduced area for shifting agriculture. The cropping period has increased and the fallow period decreased. In addition, timber needs have to be met with the expansion of teak plantations. Watershed conservation policy in1996 resettled Huaynokpit to Laksip. This has expanded the village territory as well as population. However, the most part of the additional land from Huaynokpit is classified for forest land. The additional population from Huaynokpit has been accommodated by allocation of additional agricultural land from neighboring villages. Families from Huaynokpit have a better access to market and public service in Laksip and are encouraged to explore the Luang Prabang market for their rich resources in NTFPs and to reduce their dependence on shifting cultivation.

Socio-economic changes also play an important part in the land use change. Luang Prabang, designated as world heritage in 1995, is a major destination for tourism in Laos. Laksip is only 10 km away from Luang Prabang on the national road. As a result, villagers in Laksip have good access to the increasing market in Luang Prabang. There are high demands for cash crops, including vegetables, teak and labor for off-farm work. The price of teak in the market reaches 300USD per cubic meters. Teak plantation has comparative advantages over rice production in terms of labor saving and economic profit. In addition, teak plantation is less vulnerable than rice to climate change, especially drought. Teak plantation serves as a saving and investment for children's education, house construction and family emergency. With available off-farm jobs in Luang Prabang, some farmers have already converted all their fallows into teak plantation and do not grow rice any more. The income from off-farm has increased from 2% in 1990 to 61% in 2009. The increasing share of livelihoods from off-farm sectors has helped diversify the village dependence on land resources.

consequences of land use change

Land use change in Laksip has made environmental, economic and social impacts. The land use zoning of the former Huaynokpit village for forest protection and relocation of the village to Laksip have reduced the land use disturbance in the area. As a result, forests are regenerated in most part of the former Huaynokpit village area in the south. In spite of transition to commercial production, villagers continue to conserve and grow their crop diversity under shifting cultivation. Due to the expansion of teak plantations, wild life and NTFPs have significantly declined. In the past, farmers could easily find bamboo shoots in the old fallows near their houses, but these fallows are not converted into teak plantations. Because the fallow period becomes shorter, the vegetation in the fallow does not have sufficient time to restore forests. With lack of lush vegetation in the fallow, the soil fertility for the next cycle of cropping has become very low. Moreover, the cropping period has been extended for one to two/three crops. The soil fertility is further mined. In spite of using hoe for tillage, the combination of shortened fallow periods and extension of cropping periods, especially after implementation of LUPLA in 1995, has led to land degradation indicated by declining rice yields(figure 6.7).

The expansion of teak plantation has also affected watershed service. The Houay Xon stream passing the village used to be large enough for villagers to swim. The stream water volume has become significantly smaller since the introduction of teak plantations in 1985. Villagers are worried about the effect of teak plantations on water supply. According to MSEC monitoring (de Rouw, 2010), the infiltration rate of rainfall in teak plantation in 2009 is about half that in rice fields or fallows. On the other hand, expansion of teak plantation may have increased evapo-transpiration of the watershed. As a result, the water volume has decreased. It is not clear if the rainfall has declined during this period

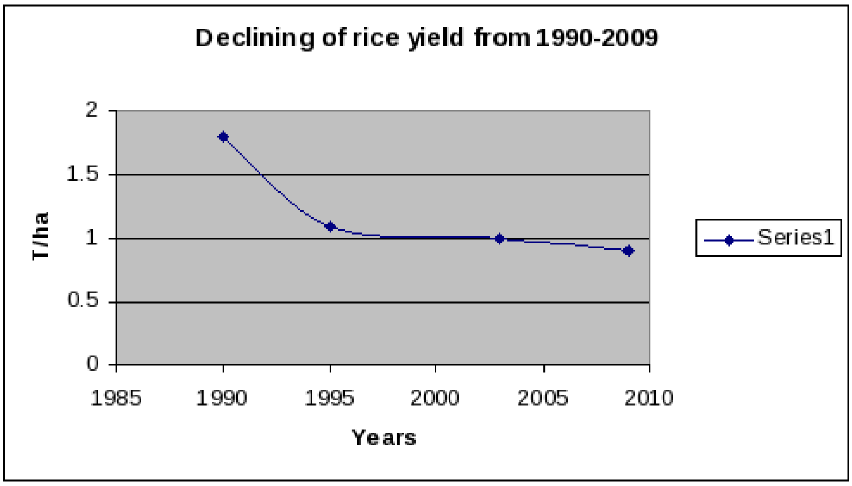

Figure 6.7: Declining Rice Yield from 1990-2009

as the data is not available. The similar impact of rubber plantation on watershed conservation was also reported by local people in Xishuangbanna, China when the research team undertook a study visit there during late December 2009.

The other environmental aspect of teak plantation is carbon storage. One of the co-authors participated in the measurement of soil carbon storage in teak plantations in Laksip, which was estimated at about 20-30 t/ha. In addition, teak plantation above ground holds much carbon. It has been reported that the total tree carbon storage in the Panamanian harvest-age teak plantations averaged 120 t/ha (Kraenzel et al 2003). Litter, undergrowth and soil compartments were estimated to contain 3.4, 2.6 and 225 t C/ha, respectively.

The land use change has resulted in the transition of a subsistence-based economy to a market economy. The traditional rice-based system has been replaced by a cash crops-based system. The expansion of teak plantation saves labor for other on-farm and off-farm opportunities. The average income in the village has increased by 70% since 1970's. Teak plantations are less vulnerable to climate change than the production of annual crops, and have contributed to the stabilization of farmers' income.

The main social impact of the land use change is on food security. Expansion of teak plantations and production of vegetables and other cash crops have significantly reduced rice production and increased village dependence on rice purchased from outside. Nevertheless, shifting cultivators traditionally depend on various sources of food from their own production as well as collection of NTFPs, and trade with outside. This case study has also found out that labor for off-farm activities increased significantly, but the labor for on-farm activities did not decrease much. As a result, villagers have become busier than before. For example, the working days per year have increased from 156 days in 1990 to 244 days in 2003. There is an increasing division of labor. According to field interviews, husbands and young adults tend to work off-farm, while women and children work on-farm. With this labor division, women and children need to work longer hours on farms than men. Moreover, tillage and more weeding are needed for short fallow. As a result, the work days for on-farm have not decreased in spite of expansion of teak plantations. In fact, teak plantations have become an important safety net in the village in case of emergencies.

CONCLUSION

Traditional long-fallow shifting cultivation had been practiced in the Laksip until the 1970's. A number of policy interventions, especially, LUPLA and watershed conservation policy, have gradually reduced the land availability for the shifting cultivation. The population dynamics associated with natural growth as well as the resettlement has increased pressure on land resources. The combined effects of the policy and the population dynamics has led to a situation of feeding more people with less land in upland Laos. Land use intensification seems inevitable. Without much improvement in technology, land use intensification is realized through shortening of fallow period and extension of cropping periods. As a result, soil fertility and crop yield have declined. Local villagers are coping with the land degradation through expansion of teak plantations. They intercrop teak seedlings with annual crops for three years and then keep the plot for teak plantation to avoid the declining crop yield during the next cycle of the cropping. Intercropping of tree crops with annual crops is also an important strategy for sustaining production and livelihoods with both short-term (annual crops) and long-term (tree crops) benefits for traditional shifting cultivators in other parts of MMSEA (Liang et al, 2009). Some farmers have harvested timber, and started over the intercropping of new tree seedlings with annual crops.

The social-economic changes are playing an increasing role in land use transition. Laksip is very close to the booming urban center of Luang Prabang. With good access to the market, the teak plantation, which has comparative advantages over rice production in terms of labor inputs and profits, is replacing rice production. Villagers are exploring the market for continuous production of vegetables and other cash crops as well as collection of NTFPs to diversify on-farm activities from shifting cultivation, which has become unproductive. Moreover, they actively take up off-farm jobs available in the urban center to reduce dependence on on-farm livelihoods. If teak plantation is considered as a kind of sedentary agriculture, the past policy interventions for promoting sedentary agriculture in upland Laos has partially realized its objective. However, the past promotion of rice terrace-based sedentary agriculture in Laksip was a failure. Some old terraces are now occupied by regenerated natural forests or teak plantations.

Nevertheless, the land use transition has induced mixed impacts. Forests in the part of forest zones are being naturally restored but forest fallows are now lost to teak plantation and can no longer produce NTFPs. The further decline of crop yield and profit may force farmers to give up cultivation of their traditional crop diversity all together. The watershed function is possibly impaired by expansion of teak plantations. A similar problem has also occurred in parts of Yunnan China where tree plantation is expanding rapidly (Liang, et al, 2009). The potential of teak plantation as a carbon storage may be explored to mitigate climate change. Livelihoods are diversified from on-farm to off-farm and from subsistence to cash crops. Local income has increased but the work load has also increased. There is increasing dependence of food security on market, but the teak plantation is less vulnerable to climate change and market risks than annual crops and may serve as a safety net for local people.

In comparison with other study sites in MMSEA, the traditional subsistence-based shifting cultivation is in transition to a market-based cash cropping system (Rerkasem, et al, 2009). Plantation of economic trees and timber trees such as rubber, tea, and alder in the fallow is a major trend in Yunnan, China similar to the trend in Northern Laos. The horticulture and tree plantation are also expanding in Northeast India. Annual cash cropping in fallows is dominant in Northern Thailand. Further assessment is needed to understand the trend and drivers of the land use transition and the role of policy interventions as well as adaptive capacity of local farmers in response to the policy interventions.

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7

COMPARISON OF GLOBAL DEM DATA FOR HYDROLOGICAL ANALYSIS OF MEKONG BASIN

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ABSTRACT

This paper describes comparison of a number of DEM sources to develop an elevation data set for the upper middle reaches of Mekong basin, upstream of Kratie in Cambodia and downstream of China. The final elevation data set adopted is a modified Global Mapping Project elevation data set based on a drainage enforcing algorithm using the digitized Mekong River System. Various geomorphologic parameters such as length ratio, bifurcation ratio, stream lengths and densities of different stream orders are computed from GTOPO30, HYDRO1K, GLOBE and Global Mapping Project data sets and are compared with the properties extracted from digitized river network to assess their applicability for hydrological analysis. Stable Horton Ratios could be calculated for different stream orders from most of the DEMs for catchment wide data, regional data and sub-catchment data. Thus the data sets represent the natural drainage accurately and are applicable for hydrological and climatological studies. However, modifications near the vicinity of rivers would be required for carrying out detailed simulations such as inundation modeling.

INTRODUCTION

Hydrological characteristics of a basin are expected to be governed to a great extent by the climate, topography, geology and land cover. With global data sets reflecting many of these characteristics becoming easily available and updated regularly to reflect more realistic ground truth conditions, it is important to investigate the adequacy of such data to classify hydrological characteristics of basins which are poorly gauged and observed. In this paper, the geomorphologic characteristics of Mekong basin are studied. The objective of the study is to adopt a

DEM for hydrological studies and to compare geomorphologic indicators extracted from different digital data sets that can be used in the characterization of the catchment.
Geomorphologic characteristics are known to reflect the basin scale catchment hydrologic responses and many investigators have studied the relation between the geomorphology and catchment hydrology (Rodriguez-Iturbe and Valdez,1979 , Abrahams, 1984, Gupta et. al, 1986). The most common parameters used in the characterization of geomorphologic properties are the Horton's ratios that identify geometric progression of stream ordering laws given by the Bifurcation ratio (R_B), the Length Ratio (R_L) and the Area Ratio (A_R) where the Bifurcation ratio is defined as the ratio of number of streams of one order to the number of streams of next higher order while the Length Ratio is defined as the mean length of the streams of one order to the mean length of the next lower order. Similarly the Area Ratio identifies the ratio of average areas drained by streams of successive order. They can be written as Bifurcation ratio: $R_B = N_(w-1)/N_w$, Length ratio: $R_L = L_(w+1)/L_w$, and Area ratio: $R_A = A_(w+1)/A_w$where w is the stream order. The Length ratio and bifurcation ratio are two of the most common indicators used in practice.
The extraction of stream networks from DEM is well established and the algorithms are included in many GIS software as standard routines. The general approach is to calculate the flow directions from each mesh according to the steepest gradient and then to develop the flow paths according to the flow accumulation. In the process, it is invariable to meet local sinks and in order to ensure that water does not stagnate or accumulate within the catchment, these sinks are filled up to the minimum required levels to ensure flow out of the catchment. Depending on the accuracy of the DEM, coarseness of the dataset, distribution of sinks, etc., the resulting river network could be quite different from the actual river network. Further, in large catchments, rivers may also be altered by human activities. Many physically based distributed hydrological models rout the overland and subsurface flow according to the steepest descent as determined by the elevation data. Therefore it is necessary to ensure the river network derived from the elevation data sets match with the actual river networks so that time lag, which refers to the lag time between the rainfall peak and the discharge peak, the peak flows, etc., are maintained, which are especially important in flood forecasting applications. To ensure such correspondence, several techniques can be employed. One is to merge a digitized river network obtained independently from Satellite or other sources with lower el-

evation along the river course with an existing elevation data set so that the resulting DEM would always generate a river network closely matching the actual river network. This procedure can be made more realistic considering the distribution of valleys and hills along the river courses and adopting iterative procedures to nudge DEM so that the resulting river networks match the actual river network.

MEKONG BASIN AND THE HYDROLOGICAL ANALYSIS NEEDS

The Mekong River is 4200 km long covering 795,000 square km. Its annual discharge is around 475 billion cubic meters. The difference between low flow and high flow of the river is about fifteen-fold, and this fact governs many water resource considerations in the basin. The Mekong basin is generally sub divided in to 7 main regions as follows,

- Upper Mekong, mainly steep gorges in China
- Northern Highlands, in Burma, northern Thailand and northern Lao PDR
- Eastern Highlands, in southern Lao PDR and Vietnam's Central Highlands
- Korat Plateau, the driest and flat section mainly in northeastern Thailand
- Southern Uplands, a small section of southern and western Cambodia
- Lowlands, including most of Cambodia bar the Delta section
- Delta, including southeastern Cambodia and southern Vietnam

Added to this diversity of natural catchment characteristics and rainfall distributions, the uneven distribution of population, economic development, resources, population makes it possible to test hydrological models for flood, low flow forecasting and water resources management under many different conditions.

In the present study we are interested in the hydrological modeling of the region from the downstream of Chinese border and the upstream of Kratie hydrological station. The region of interest within the catchment is shown in Figure 7.1. The present analysis is restricted to this area.

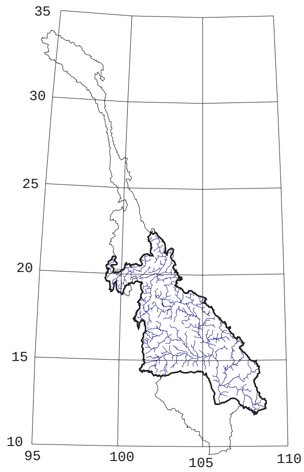

Figure 7.1: The Mekong basin with the study area and digitized river network

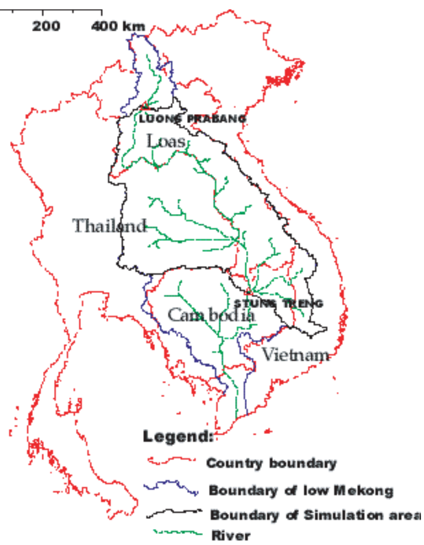

Figure 7.2: Catchment for Hydrological Simulation

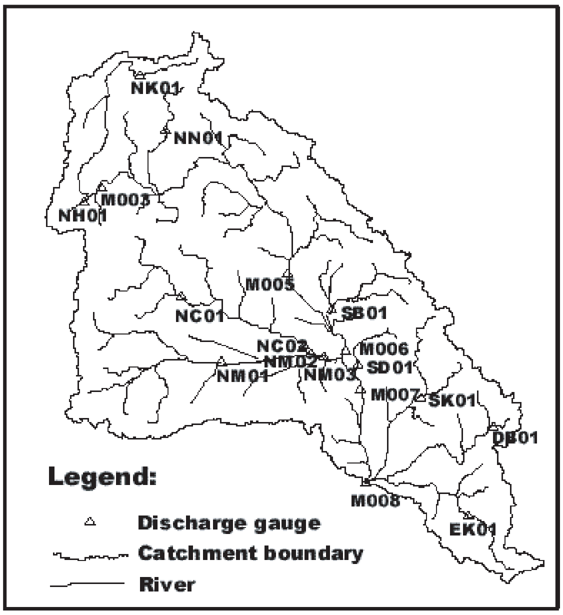

Figure 7.3: River Gauges used in the assessment

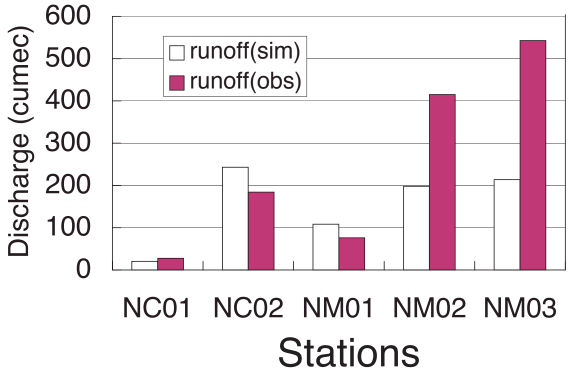

Figure 7.4: Comparison of Simulated and Observed Annual Flows

In a previous study, an area of the Mekong basin extending from China-Lao PDR boundary marked by the Luang Prabang, to the Stung Treng gauging station in Cambodia was modeled using a hill-slope-river network type distributed hydrologic model (Herath and Yang, 2000). The model region was set up using 1 km mesh data from Global Mapping Project (version 0). The catchment area within these two gauging stations covered an area of 402,636 sq. km., and is shown in Figure 7.2. In that study, river discharge data observed at locations shown in Figure 7.3 were used for model performance assessment for a period covering 2 years, from 1989 to 1990, where daily stream discharge hydrographs were compared with that from simulation. In the simulation, hourly time steps were used in the computations in keeping with process modeling requirements and the results were integrated to daily scale for comparison with observations.

The simulation results showed that while the general agreement of hydrographs was good, the flow from flat areas, especially the contributions from Thailand had the biggest errors (Herath and Yang, 2000). Figure 7.4 shows the observed and simulated discharges for the Korat province of Thailand where the observed and computed discharges vary significantly along the stream. In this flat terrain river networks generated from the DEMs tend to be quite different from actual networks. In addition, Kinematic wave routing schemes used in the hydrological model is dependent on the elevation gradients and flows tend to stagnate in the near zero gradient terrain, compounding the errors. Therefore, for hydrological modeling, it is important to modify the elevation data to result in stream networks that can adequately drain the catchments. In the following sections we analyze the DEMs from different global data sets in order to assess the representative ness of derived river networks. We also investigate the robustness of estimating geomorphologic characteristics of the basin from the DEMs and the possible use of them in basin characterization.

RIVER NETWORKS FROM DIFFERENT GLOBAL DATA SETS

Global DEM datasets

There are a quite number of elevation data in digital format that can be used in the hydrological applications at global, regional and country levels depending on the available resolutions. For the Mekong Basin, the best available data are the 30" arc grided elevation data available at global scale. There are several 30" arc data sets available free of charge downloadable over the Internet while a number of them are still at developing stage. Global Land One-kilometer Base Elevation (GLOBE) digital elevation data set had been developed by an international group of scientists affiliated with Committee on Earth Observation Satellites (CEOS) starting from more than 10 years ago. The GLOBE effort continues to evaluate and assimilate existing digital elevation data to the global data archive.

Another effort of compiling global data is carried out with the advocacy of Japan Ministry of Construction under the title 'Global Mapping Project' where National Mapping Organizations of more than 81 countries are participating under the recommendation of UN. The version 1.0 of these data, certified by the participating countries is now available. For the Mekong basin, currently available data covers most of the study areas of interest except for a small portion covering Myanmar.

DEM generated from GTOPO30

Most widely used elevation data set at present is perhaps the GTOPO30, released in 1977 by USGS developed over a 3 year period through collaborative effort led by staff at the U.S. Geological Survey's EROS Data enter (EDC). Complete global coverage and free availability over the Internet had made the data set to be popular and widely used. Except for elevation data covering United States, Japan, New Zealand, Italy, Peru and Australia, for which the data have been provided by those countries to either GLOBE or GTOPO30 much of the other data had come from either Digital Terrain Elevation Data (DTED), the digital terrain data produced by the U. S. National Imagery and Mapping Agency (NIMA), and its precursors (primarily the Defense Mapping Agency, and before that the Army Map Service) or the Digital Chart of the World (DCW) data set which is a vector cartographic data set based on the 1:1,000,000-scale Operational Navigation Chart (ONC) series. The DCW and the ONC series are also products of NIMA. For the Mekong region most of the original DEM data come from the NIMA DTED data set. Figure 7.5 shows the river network generated from the GTOPO30 dataset for the study area. In comparison with the actual river network as seen from the digitized data in Figure 7.1 the differences of river networks in the Korat province in Thailand is clearly visible. The generated network has introduced a major tributary in Thailand and also the shape of the confluence of the Mun River

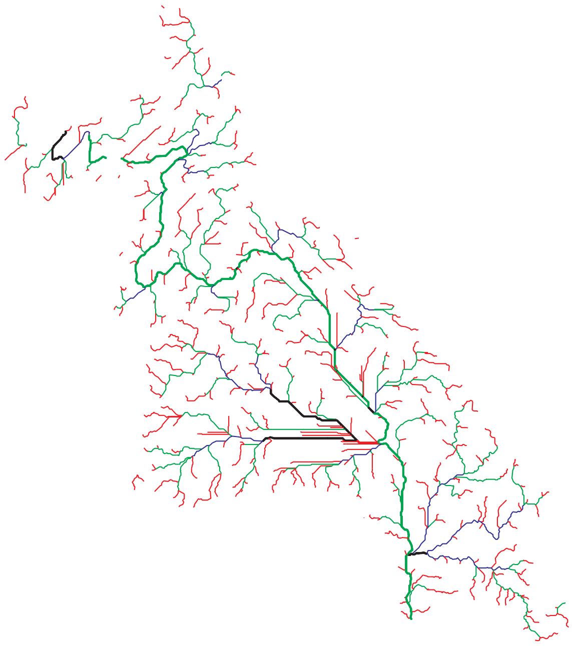

Figure 7.5: River network generated from GTOPO30 data set

system with the Mekong is different from the actual river network. In addition, upstream (near the Chinese border) rivers generated flow out of the catchment in opposite direction from the actual rivers.

DEM generated from Hydro 1K data set

HYDRO 1K is a data set derived from GTOPO30 data set but is especially designed for hydrological analysis. The data set is ensured to be hydrologicaly correct, in the sense that stream networks derived from the data set agree with the digitized actual stream network. To achieve this consistency an iterative procedure is adopted in adjusting the DEM and defining internal sinks for elevation filling (Danielson, 1996). Where the data does not match the drainage network when compared with actual drainage patterns, DEM has been edited to ensure water accumulation along the actual streams. The stream network generated from this data set shown in Figure 7.6 agrees quite well with the actual stream network shown in Figure 7.1 in the Korat Province of Thailand. In order to preserve the projected areas, Lambert Azimuthal Equal Area projection is used in the hydro1K data set. However, most of the hydrological and infrastructure information that need to be used in water management and flood forecasting application are available in

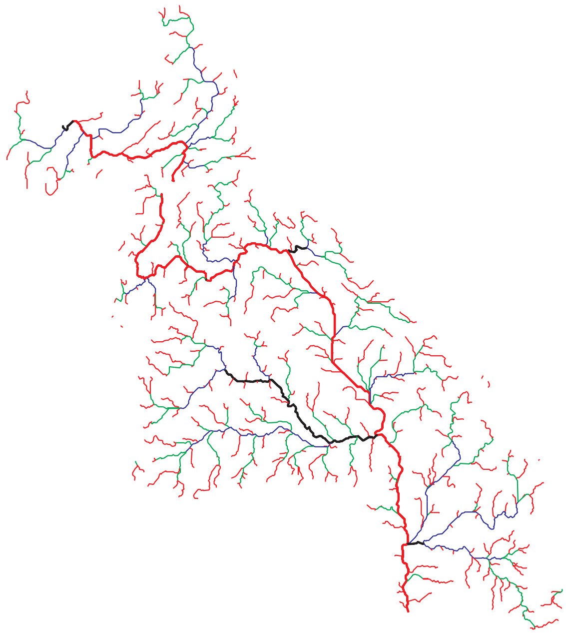

Figure 7.6: River network generated from Hydro1k data set

UTM coordinates. When the original HYDRO 1K data are projected to UTM coordinate system, the resulting stream network does not follow the actual stream paths, bur rather a large number of disconnected stream segments result from the generation. The likely explanation for this discrepancy is that original elevation data at some grids along the streams differ considerably from the adjacent ground elevations and that interpolation accompanied in projection transformation gives rise to a large number of local sinks. The impact can be minimized using a nearest neighbor interpolation scheme rather than a linear interpolation scheme while changing projection scheme. The results shown in Figure 7.6 are generated in this manner. However, as seen from the figure two different river systems have resulted with the upstream portion draining in the opposite direction compared to the actual river flow.

River Network from Global Land One-kilometer Base Elevation (GLOBE)

The complete 30 arc second global elevation data are now available under the GLOBE program. the river network generated from this data set is shown in Figure 7.7.

As seen in Figure 7.7 this data set produced a river network that is closest to the original network after that produced by Hydro 1K data

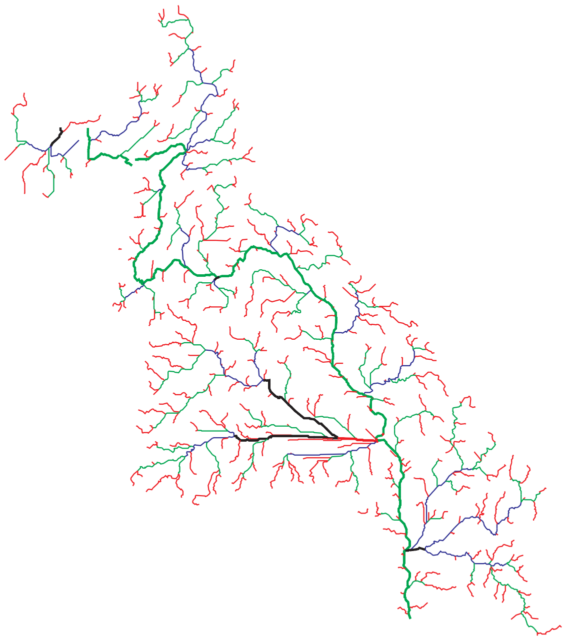

Figure 7.7: River network generated from GLOBE data set

set. However, there are upstream discontinuities as well as additional tributaries in flat areas such as in Korat Province.

River Network from Global Mapping Project

The elevation data made available by the participating countries at the end of 2002, were down loaded from the ISCGM web site and were used in compiling the GMP elevation data set. The river network generated from this data set is shown in Figure 7.8. For clarity as in the other cases too, streams of order II and above are only shown here.

From the Figure 7.8 it can be seen that the resulting stream network closely resemble that derived from GTOPO30. In the upstream portion discontinuities are slightly different from the GOPO30, probably due to the use of Hydro 1K data for the Myanmar portion as it was missing from the GMP dataset.

CREATING DRAINAGE ENFORCED ELEVATION DATA

A rather substantial amount of work has been done in the recent past on adjusting DEM data for hydrological applications. They vary in the algorithms used to adjust the elevation values so that all the flow

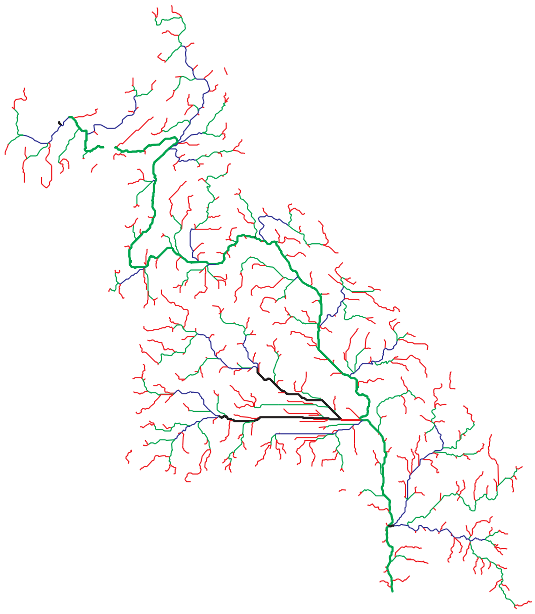

Figure 7.8: River network generated from GMP data set

accumulates along the actual stream network. An algorithm based on ANUDEM program developed by Michael Hutchinson (Hutchinson and Dowling, 1991) is incorporated into Arc/Info GIS software in performing this forced adjusting. In order to carry out this correction, first a vector map of the stream network directed towards the catchment outlet and a map of the catchment boundary should be prepared. Such a directed vector map including order I streams prepared from the digitized data are shown in Figure 7.9. The original DEM is then adjusted based on this stream network iteratively until the derived flow accumulation closely follow the given flow accumulation pattern.

The Figure 7.10 shows the stream network generated from Global Mapping Project DEM, adjusted using the stream network shown in Figure 7.9. As can be seen in the Figure 7.10 the algorithm can force the DEM filling in a manner that result in flow directions and accumulation characteristics that resemble real stream network.

GEOMORPHOLOGIC PARAMETERS OF MEKONG BASIN

As discussed earlier, the most common parameters used in the characterization of geomorphologic properties are the Horton's ratios that identify geometric progression of stream ordering laws given by the Bifurcation ratio R_B, the Length ratio R_L and Area ratio: R_A. The Length

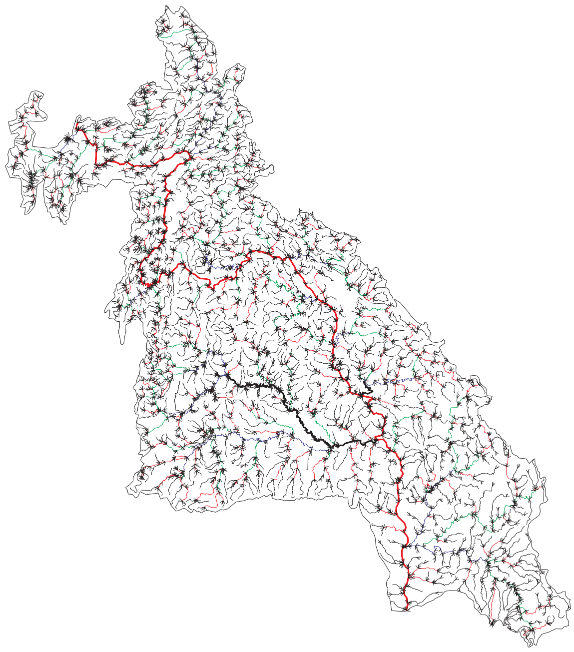

Figure 7.9: Arranged directional order I stream network

ratio and bifurcation ratio, the two of the most common indicators used in practice, are calculated for the study area.

The Table 7.1 shows the cumulative lengths for each stream order obtained from different data sets. The Global Mapping Project (Modified) refers to the elevation data set modified from the drainage network. From the Table 7.1 it is clear that there is no significance difference among the different data sets in terms of total stream lengths.

The Table 7.2 show the R_B and R_L computed from different data sets for the study area. It is seen that while the R_B ratios are very close to each other from all the data sets, significant differences can be found in the R_L values.

The Figures 7.11 shows the number of stream channels for each stream order obtained from different data sets. The ratio R_B is fairly constant at around 4.5 for all the data as also shown by the nearly linear relation of the cumulative values in the Figure 7.11. As for the R_L, the digitized and the GTOPO30 values show some fluctuation compared with the other three data sets, which show a close set of values around 2. The cumulative values of the stream lengths at different stream orders are shown in Figure 7.12.

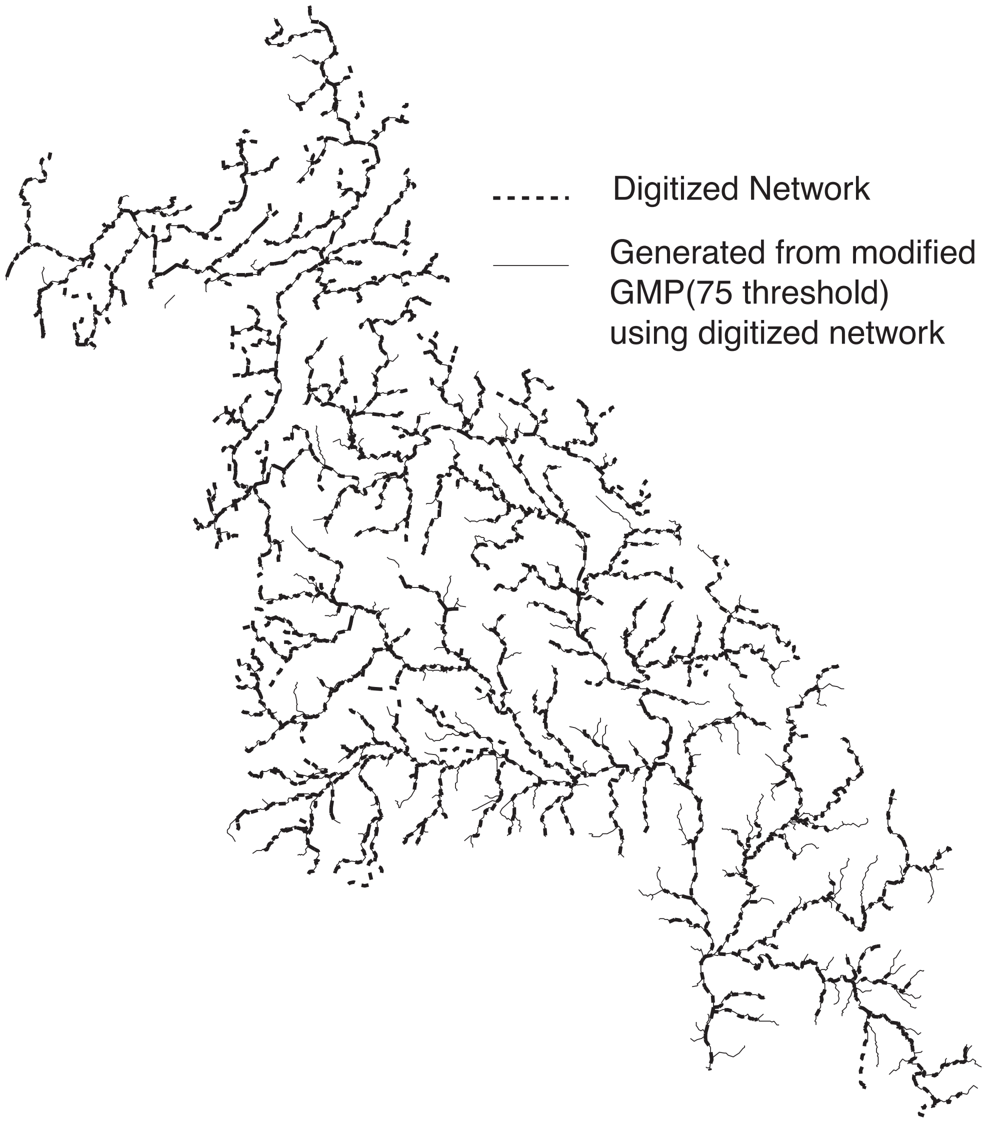

Figure 7.10: Comparison of generated and actual stream network (for clarity only streams of order II and above are shown)

Table 7.1: Total stream lengths from different data sets

Data Set	Total Stream links	Total Stream length	Order I Stream length	Order II Stream length	Order III Stream length	Order IV Stream length	Order V Stream length
Digitized	3269	51411279	32035964	8692480	5832093	2364418	609679
GTOPO30	3270	41367963	22283607	9412167	5578750	1868606	518788
HYDRO1K	3349	39088517	19581709	9590887	5048094	2561230	520671
Globe	3315	39796590	20353777	9569485	5010366	2515904	480132
GMP	3275	39899869	20571368	9630713	5042684	2367826	466776
GMP (Modified)	3286	39155993	19187861	9489018	5469147	2527705	563068

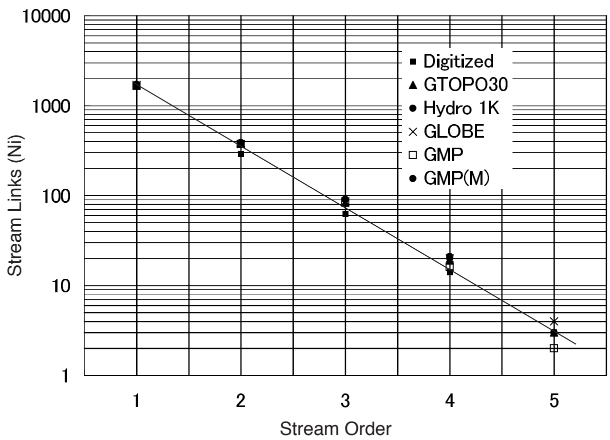

Figure 7.11: Number of stream links from different data sets

Table 7.2: Horton ratios for the study area from different data sets

Data Set	R_{B1}	R_{B2}	R_{B3}	R_{L1}	R_{L2}	R_{L3}
Digitized	5.81	4.60	4.50	1.58	3.09	1.82
GTOPO30	4.36	4.56	4.42	1.84	2.70	1.48
HYDRO1K	4.45	4.27	4.33	2.18	2.25	2.20
Globe	4.51	4.36	4.30	2.12	2.28	2.16
GMP	4.46	4.20	4.50	2.09	2.20	2.11
GMP(Modified)	4.44	4.44	5.25	2.20	2.56	2.43

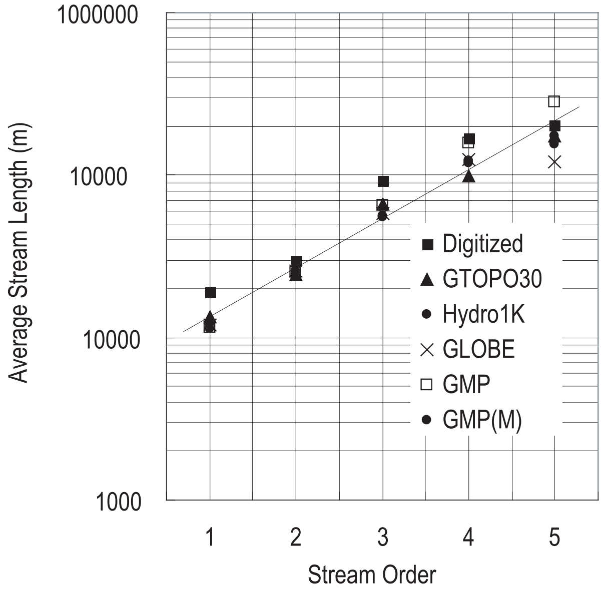

Figure 7.12: Stream lengths of each order different data sets

EFFECT OF THRESHOLD VALUE

A threshold value of flow accumulation is generally used to identify the initiation of a stream. Depending on this threshold value, stream density and hence the network density is determined. The Figure 7.13 shows three stream networks that result from different cut-off threshold values. The sparse network corresponds to a stream network resulting from a 75 pixel (sq.km.) flow accumulation value. The total number of streams produced by this network is similar to the digitized network and has been used in the comparisons in the previous sections. The next figure is derived using a threshold value of 50 pixels and the final one is derived using a threshold value of 15 pixels. The relevant geomorphological parameters of the stream networks are shown in Tables 7.3 to 7.5. As can be seen from the tables the Horton Ratios R_B and R_L are very stable and converge to the same value except for the case of stream order V links for GMP75 which is a result of very small number of links at that order. From the above, it can be concluded that irrespective of the threshold value and the resulting density of the stream networks, stable Horton Ratios can be derived from DEMs.

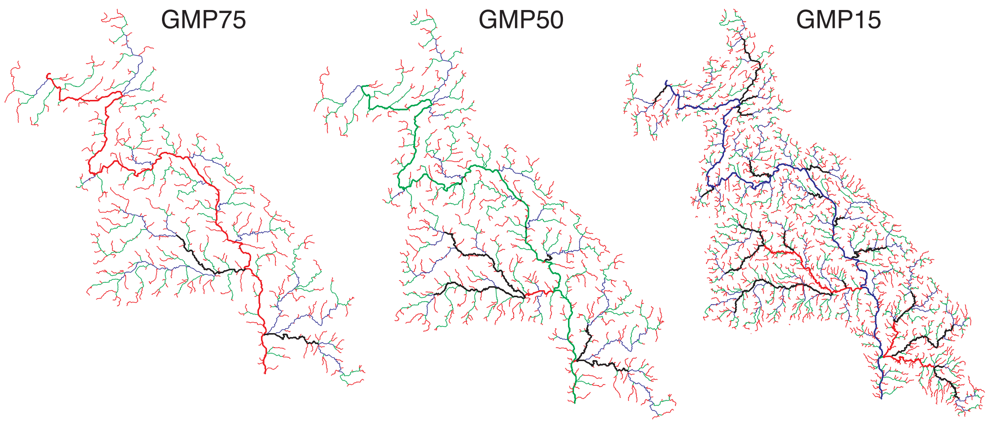

Figure 7.13: Stream networks from 75, 50 and 15 pixel threshold flow accumulation

Table 7.3: Stream parameters derived for networks with different threshold values

Data Set	Length of Order I Streams	Length of Order II Streams	Length of Order III Streams	Length of Order IV Streams	Length of Order V Streams
GMP75	20571368	9630713	5042684	2367826	466776
GMP50	23581502	11010220	6497643	2725629	1170533
GMP15	39903665	19046677	9324266	4991647	2596818

Table 7.4: Stream numbers derived for networks with different threshold values

Data Set	No. of Order I Streams	No. of Order II Streams	No. of Order III Streams	No. of Order IV Streams	No. of Order V Streams
GMP75	1687	378	90	20	3
GMP50	2379	541	125	24	5
GMP15	7131	1590	361	86	20

Table 7.5: Horton Ratios derived for networks with different threshold values

Data Set	R_{L1}	R_{L2}	R_{L3}	R_{L4}	R_{B2}	R_{B1}	R_{B3}	R_{B4}
GMP75	2.09	2.20	2.11	1.31	4.46	4.20	4.50	6.67
GMP50	2.05	2.55	2.18	2.06	4.40	4.33	5.21	4.80
GMP15	2.14	2.16	2.25	2.24	4.48	4.40	4.20	4.30

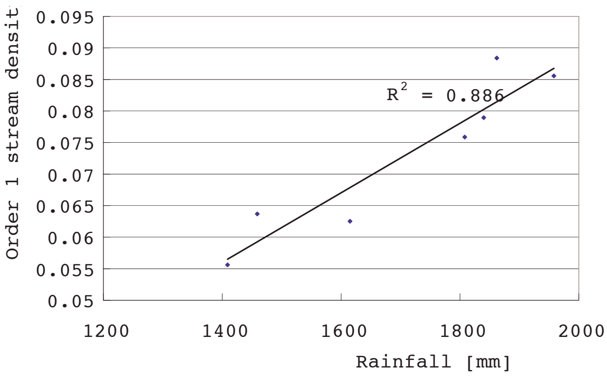

Figure 7.14: Relation between basin rainfall and order I stream density

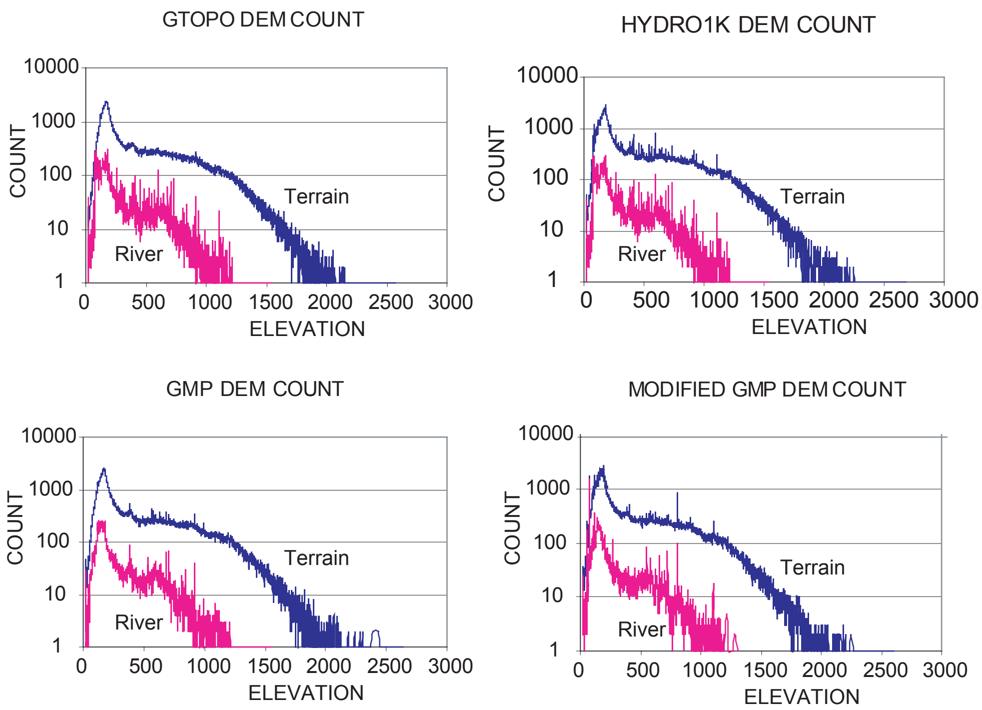

Figure 7.15: Elevation histograms corresponding to different data sets covering the terrain and the streams

CONCLUDING REMARKS

The analysis of several DEM data sets show that river network derived from the DEMs may vary from the actual river system in low gradient areas due to low spatial and vertical resolution of data sets. Imposing river networks elevations on the DEM seems to ensure that re-calculated networks match with the actual systems. However, as seen in the case of Hydro 1K data set, interpolation of data, as in the case in projecting to a different coordinate system, may disrupt the orientation and flow directions. Drainage enforcing algorithm used has performed well and the GMP data set modified by the enforcing algorithms could produce the river networks accurately.

The Horton's Ratios computed from different global data sets have similar values over the whole upper Mekong basin. The tests carried out with separate regions and small sub catchments too have given similar R_B and R_L parameters within the basins. A rather interesting linear relation between order I stream density and catchment average annual rainfall can be seen in Figure 7.14.

Considering the differences of R_B and R_L obtained from the digitized data compared with digital data sets, the different global data sets appears to share the same information base. For flood modeling, it is necessary to generate the river networks and compare them with the actual rivers either obtained from satellite data or from field surveys. When they deviate from the actual river networks, the decision to alter the DEM will depend on the assumptions of the particular hydrologic model used in the simulations. Although the drainage networks differed considerably according to distribution of sinks and flow directions, the underlying DEMs do not differ much except in the vicinity of the rivers, even after modifying with drainage enforcing algorithms. This was also evidenced by the closeness of the Horton's Ratios estimated from different DEMs.

The histograms of different DEMs are shown in Figure 7.15 together with histogram of the river elevations. As can be seen from the figure the overall distribution of elevation among the data sets are very similar. The differences in river networks generated from each data set arise due to small localized differences while the main terrain characteristics remain same. Compared to GTOPO30, Hydro 1K shows more spikiness. Similarly, the modified DEM of the GMP for the area shows more spikes where the terrain has been modified to ensure the resulting river network. These changes in the histogram can be taken as guide in accepting the modifications carried out on a DEM to enforce flow accumulation patterns that correspond to a given stream network.

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8

RAPID REDD PERSPECTIVE FOR CLIMATE CHANGE MITIGATION AND ADAPTATION

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ABSTRACT

Rewards and recognition related to REDD (Reducing Emissions from Deforestation and Forest Degradation) compensate countries and communities that keep their forests intact for atmospheric carbon sequestration and as carbon sinks. REDD, as an innovative mechanism, has been generally supported at the recent UNFCCC Conference of Parties (COP) conferences - including Bali in 2007, Copenhagen in December 2009, and elsewhere. Considerable commitment for funding pertinent programmes and projects is underway, primarily for preventing the ongoing massive deforestation and forest degradation in tropical developing countries, essentially for climate change mitigation. It should also serve as an adaptation action, taking note of the vulnerability of these countries, where forests are a rich repository of biodiversity and critical ecosystems services. Conserving and restoring them is unlikely without addressing various constraints and conflicts and without pro-actively involving the array of stakeholders. That should be possible with the Payment of Environmental Services (PES) to the stewards of forests, watersheds and related renewable resource assets, on which millions in Mekong and elsewhere are dependent, especially for food, fuel, fibre and livelihoods.

Enabling policy and institutional environment is required with contextual considerations of diverse landscapes in order to deliver climate change mitigation and concurrently contribute to adaptation and sustainable social and economic development. Capturing the co-benefits of REDD and the challenging opportunities of emerging carbon markets and complementary financing mechanisms must not be missed, despite the risks and uncertainties regarding which appropriate modus operandi must be designed up-front. Fast facts about REDD, REDD plus and REDD Readiness initiatives provided in the paper are a basis for road-mapping strategic scenarios and policy perspectives for making PES and REDD a lasting success and not merely a short-term

source of funds before the funders gets frustrated or the beneficiaries become forgetful.

Key words: MAD (Mitigation, Adaptation, Development), Climate Change, REDD

REDD RATIONALE

Deforestation and forest degradation account for 17% of the global greenhouse gas emissions. Forest sector mitigation measures have gained importance in the climate change debate as these are considered to be cost effective means to combat global warming while providing an array of social, environmental and economic benefits. Also concurrently enabling adaptation of vulnerable communities and countries to climate change and promoting development through PES (payment for environmental services).

Preventing deforestation is potentially one of the simplest ways to reduce global carbon emissions and related climate change. Carbon emissions from deforestation account for more than all the world's trains, cars, buses, aeroplanes and ships combined. Reducing deforestation and land-degradation would be a quicker and cheaper way of reducing emissions than many alternatives. Paying people to not to do deforestation does not need any costly new technology, so that avoided deforestation should be relatively easy to attain, provided the stakeholders are compensated, for which the REDD mechanism has been devised. Apart from reducing carbon emissions, keeping forests intact also prevents soil erosion, improves the quality of water, helps regulate rainfall and ensures biodiversity.

REDD is being designed to address the complicacies of the convoluted Clean Development Mechanism (CDM) of the Kyoto protocol. Since 2006, the CDM has allowed developing countries to sell carbon offsets for adopting green technology, for example through switching to solar or wind energy, or planting trees. However, the Kyoto rules do not allow countries to sell offsets from avoided-deforestation schemes. Planting new trees are qualified, but refraining from cutting down existing trees are not.

Estimates for the cost of halving the rate of deforestation (and therefore reducing global emissions by as much as 9%) range from $7 billion to $28 billion a year. Assuming an emissions reduction by 20-40% relative to 1990 levels, however, the scale of the investments required by the global carbon market will be worth $118 billion a year. If 10% of the reduction in emissions was achieved by purchasing REDD offsets, forest-carbon credits will be worth $11.8 billion a year. The UN, the World Bank and governments in several countries, including Australia, Britain and particularly Norway, have already provided around US$800m over the past two years to get REDD projects going. Such early funding ensures projects are already in progress in anticipation of a new global climate agreement. Even as the world failed to reach a formal deal in Copenhagen, REDD schemes were mostly welcomed and supported by major countries. REDD has thus started off as a series of funded projects, with a vision for forest-carbon credits in the marketplace.

REDD schemes will enable the distribution of funds that they generate. Governments could launch national initiatives to prevent deforestation, sell credits and direct the proceeds to appropriate activities. That should also pre-empt any "leakage" of deforestation, where a forest protected in one area shifts deforestation to another, this would become easier to control. But governments will need to distribute some of the money on the ground-especially if the locals feel they have every right to cut down their trees. PES are an appropriate mechanism, so that REDD involves local communities and civil society. Given that the basic principle of REDD is to establish a financial link between those who will benefit from preserving forests and those who must ensure the forests' survival, it is an economically sound approach, which should flourish in the years to come.

REDD, REDD Plus and REDD Readiness

Forests and other terrestrial sinks remove 2.6 GtC of CO_2 annually from the atmosphere (AR4). Deforestation and other land-use activities emit 1.6 GtC annually (AR4) and the forest sector, mostly deforestation, accounts for 18% of the total anthropogenic GHG emission. The concept of REDD Plus brings in conservation, sustainable management and enhancement of forest carbon stocks. Though the primary objective of REDD and REDD Plus is emissions reductions and removals, they also have the potential to deliver a range of "co-benefits", e.g., poverty alleviation in forest areas and ecosystems conservation. REDD/REDD Plus phases include: Readiness Phase (Phase 1), Policy implementation Phase which also include proxy based compensation for emission reductions and removals (Phase 2), and results based compensation mechanism-implementation phase (Phase 3). Among the REDD Readiness mechanisms are the World Bank Forest Carbon Partnership Facility (FCPF), UN-REDD programme, and initiatives by various governments and foundations to support readiness activities. Over the period leading up to the Copenhagen negotiations, REDD Readiness mechanisms in addition to technical and capacity building issues, have started addressing issues concerning the implementation of REDD programmes. REDD/REDD Plus is an innovative initiative for financing carbon sequestration for climate change mitigation, for promoting good governance and climate change adaptation for human wellbeing and livelihoods through sustainable access to multiple forest products and services.

REDD Readiness process involves a wide-ranging scope of work. No single programme can cover all the components. The UN-REDD programme and FCPF have therefore been working together to define the components of Readiness and ensure that the funding for the different aspects of Readiness is coordinated. The Bali Action Plan (BAP) and its follow-up through Copenhagen and thereafter, allows for positive incentives for REDD and enlarges it to REDD Plus by including Sustainable Forest Management (SFM) and Afforestation/Reforestation (AR). In this context, the World Bank's finance for climate change mitigation and adaptation includes Carbon Funds and Climate Investment Funds. Some of the funds specific to forest and climate change are (i) Carbon Funds, such as Bio Carbon Fund (BioCF, since 2004): Demonstrate carbon finance mechanisms for reforestation and forest protection testing ground for post-2012, including "REDD" at the project level; Forest Carbon Partnership Facility (FCPF, since 2008): Build readiness for Reducing Emissions from Deforestation and Forest Degradation (REDD)+ and Pilot performance-based payments, and (ii) Climate Investment Funds, such as Forest Investment Program (FIP): Pilot investment models for REDD; Growing Forests Partnerships (GFP, since 2008): Empower local stakeholders to engage in local, national and global processes on forests.

The FCPF has pioneered the REDD readiness preparation process, and currently it has 37 country participants, 10 donor participants, five carbon fund participants and six observers. It is a ten year Facility to help developing countries build capacity to reduce greenhouse gas emissions by protecting their forests. The industrialized countries have already pledged nearly US$200 million to support the Facility, which consists of two separate finance mechanisms, each with its own trust fund for which the World Bank acts as the Trustee. A Readiness Mechanism (target size: US$100 million) is for assistance to approximately 20 countries so far for preparing themselves to participate in a future, large-scale system of positive incentives for REDD. The Carbon Finance

Mechanism (target size: US$200 million) will enable an initial group of these countries that will have successfully participated in the Readiness Mechanism to pilot incentive payments for REDD.

The REDD Plus interventions are not only for carbon but also an opportunity to protect, manage and increase forests for better provision of all their services. While carbon in the forestry sector is significant, the issue of governance and community participation must also be addressed to ensure benefits to forest users. The experience from Clean Development Mechanism (CDM) forestry reinforces the need for simple and robust methodologies, modalities and procedures for the REDD Plus process and for the REDD Readiness funds and related climate change investments. The participating countries need to develop transparent, equitable and accountable benefit-sharing mechanisms for distribution of the carbon-based revenues. The MRV (Measurement, Reporting and Verification) system should be credible and comprehensive so as to not only account for the carbon, but also take into consideration the social and environmental parameters, including the recognition of the role of communities. The participating countries would benefit by cooperating among themselves to learn from past experiences in forest management, governance and tenurial reforms. In order to cover all the possible mitigation options and to accommodate varying national circumstances, there is a need for market-based and fund-based approaches to co-exist to support a full implementation phase of the REDD Plus activities, more so after the Readiness and pilot phase activities.

REDD, WATER & CLIMATE CHANGE

Forests contain a substantial part of the planet's carbon. Climate change and forests are intrinsically linked: climate change is a threat to forests, and protecting forests from conversion and degradation helps mitigate the impacts of climate change. SFM is a means of achieving the goals outlined by the United Nations Framework Convention on Climate Change (UNFCCC) with respect to forests: using forests for carbon capture and storage, thus reducing the emissions of greenhouse gases — in this way, forests become part of a climate strategy for mitigation; and using forests and trees as part of a strategy to cope with impacts of climate change — in this way, forests become part of a climate strategy for adaptation. REDD mechanism would provide a global incentive for the conservation and sustainable management of forests.

REDD in developing countries is a new financial mechanism for the post-2012 climate change regime under the UNFCCC. REDD represents an unprecedented development in the creation of an international mechanism to help internalise the carbon-related ecosystem services from forests and could make a significant contribution to addressing the global climate change challenge.

REDD projects are being developed in several countries and could benefit local communities through PES for participating in SFM and related REDD activities-though often this is subject to their land tenure record and thus access to forest carbon funds. The estimated potential greenhouse gas reductions from forestry measures are up to 6.7 giga-tons of carbon dioxide (CO2) (IPCC 2007). Forests thus play a key role in tackling climate change. In addition, REDD can contribute to biodiversity and watershed protection among its co-benefits through the payment of environmental services of forests involving (i) biodiversity conservation, (ii) watershed protection, (iii) carbon sequestration and protection of air quality, (iv) control of land degradation and desertification, and (iv) protection of landscape and scenic values, among other benefits.

The earth's four billion hectares of forest store 633 billion giga-tons of carbon. This means that forests store more carbon than the amount of carbon in the atmosphere. Forests as major carbon sinks influence and mitigate climate change, particularly the biodiversity and biomass rich tropical forests. They are also more fragile and vulnerable to climate change. Adaptation and resilience are therefore crucial issue, both for environmental services and forest dependent livelihoods. Adaptive capacity can be strengthened through institutional linkages across boundaries of countries concerned, their governments, private sector and civil society, including local community organizations. Agro-forestry for climate change adaptation and mitigation can provide more benefits than pure plantations, almost twice as much, as recently revealed in Sorong, Indonesia. Through their sustainable management, forests can contribute to alleviating poverty, safeguarding biodiversity, providing the broad range of goods and services for present and future generations, in the context of a changing climate.

Forestry, as one of the more important climate change mitigation and adaptation tools, has been receiving due attention in some countries. An example is China, where the State Forestry Administration has published a plan in November 2009 which sets forth the basic principles, targets, and initiatives to be taken in light of climate change. The five basic principles in the plan combine the targets of forestry development with the national strategies on climate change, increasing forest size and improving forest quality, increasing carbon trading and controlling emissions, combining government guidance with social participation, slowing down climate change, and adapting to the change. The three targets are: planting more than four million hectares of forest annually and make the national forest coverage rate reach 20 % by 2010; planting more than five million hectares of trees each year and making forest coverage reach 23% by 2020; increasing forested area by 47 million hectares more than that of 2020 and make the forest cover over 26 % by 2050.

India has prepared a Green India Plan with the goal of 6 million hectares to be planted with trees, while the National Forest policy has set the target of 33% of forest cover for the country. Satellite monitoring has reported that the forest cover is indeed increasing and has crossed 23%, but there is also forest degradation in many parts of the country, for which measures are afoot. A model example is the setting up of a compensatory afforestation corpus fund of US$2.6 billion, from which resources have been released at the beginning 2009 for forest restoration and recuperation with due coordination, monitoring and review for SFM.

SFM is defined as "Stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems." The failure to implement SFM limits the capacity of forests and people to adapt to climate change. There is a strong need to strengthen commitment to achieving SFM goals through enabling institutions, stakeholder participation, good governance, valuation and valorization of forest resource assets and services, deploying forest certification systems and ensuring sufficient financial incentives.

At the same time, there is need to acknowledge the cross- sectoral context of forests, trees and people, i.e., the multiple benefits that forestry confers and the mutual interdependence of agriculture, animal husbandry, forestry and human wellbeing. Climate change will have far-reaching social and economic consequences for all the communities, including forest-dependent poor people. Adaptation must go beyond technical measures and address the human-institutional dimension of the problem. One self-reliant solution is adoption of benefit-sharing and market mechanisms, such as PES, for recognizing and rewarding forest owners and local communities as stewards - with ownership and entrepreneurship in resource management, climate change mitigation and adaptation. Institutional mechanisms for PES may help to create a win-win solution for both the users of forests and related renewable resources and the environment, and can be developed at different scales, from local to national to regional, involving communities, governments, and the private sector, with due rigour in the context of REDD and REDD+.

There is also an urgent need for modelling and assessment of the consequences of climate change and its ultimate effects on water-related stress and hazards, which would ultimately affect forest and other ecosystem services, livelihoods, and food security. The high interdependence indicates the need to exchange experience and information, and coordinate measures, in a regional trans-boundary setting. For this, it is important to develop regional knowledge bases, enhance data collection, and promote the sharing of data that already exists. One priority would be for sharing hydro-meteorological information in a regional, upstream-downstream context for the establishment of efficient early warning systems for disaster preparedness.

Both for disaster prevention and preparedness, it is timely to launch regional initiatives, such as in Mekong and Ganges basins, to study the effects of climate change on river flow, variability, erosion, and sedimentation, and water storage requirements. One approach to reducing vulnerability and strengthening local level adaptation is to use bottom-up, community led processes built on traditional knowledge, innovations, and practices. The amount, and especially variability, of rainfall presents challenges to food production, trade, and infrastructure development in the regions. The affected countries typically lack the most common response to hydrologic variability – water storage infrastructure. Until basic water security is achieved, the scale of social impacts and related economic impacts could be such that the economy, environment, and society are significantly affected. Climate change has the potential to significantly change the hydrological dynamics of the region, especially if a greater proportion of precipitation falls as rain instead of snow, as projected.

Sustainable watershed management with participatory and cooperative involvement of all the stakeholders in the process of re-greening and equitable benefit sharing is a cost-effective way to adapt forest and related resources to climate change and to harvest rainwater, enhance soil moisture and ground water recharge, and rehabilitate degraded land and improve its productivity. REDD in this context is a pro-active programme for the role of trees and forests in protecting watersheds and related climate change adaptation.

Carbon sequestration is primarily a function of biomass production, so the measurement of changes in carbon stock is relatively easy. As such, "carbon trading" has a high market growth potential, but to date, few concrete examples of payments for forest-related carbon sequestration have materialized. That is despite CDM, under which only 9 projects have been approved so far and those too are small-scale and with limited overall impact. REDD, on the other hand, could change the scenario by delivering basin based and large-scale projects.

CLIMATE CHANGE VULNERABILITY, ADAPTATION AND MITIGATION

Adaptive capacity is not equally distributed or shared worldwide. Developing countries, where a majority of the population depends on climate–sensitive sectors such as agriculture and forestry, are more vulnerable to impacts of climate change. The role of forests must be clarified and articulated in National Adaptation Programmes of Action. At present most attention and financing is focused on REDD, and, in general, on climate mitigation. Only recently has the concern for the role of forests in adaptation gained ground; this emanates from the growing recognition that climate change will happen anyway. Moreover, climate change will affect the most vulnerable ecosystems and poorer regions. The people living in these areas usually contribute least to climate change, but may suffer most from its effects, as they usually lack the means to adapt. It is also well-evidenced that trees and forests in these areas are an important safety net. Adaptation efforts will have to be closely linked to the poverty agenda.

Measures aimed at assisting forests to adapt to climate change, especially in the tropics, need to be adopted. That could include facilitating the adaptive capacity of tree species, mainly by maximizing genetic variation; silvicultural and management approaches, such as minimizing slash, reduced impact logging and widening buffer strips and firebreaks; and institutional and policy programmes, such as increasing awareness, improving fire management, participatory genetic improvement programmes for smallholders, mainstreaming adaptation into national development plans, and establishing financial mechanisms to help implement adaptation measures, taking due advantage of REDD and related funding potential for co-benefits.

The impacts of climate change on forest ecosystems are likely to be long-term and irreversible. Thus, there is a need for developing and implementing adaptation strategies to minimize possible adverse impacts. Further, there is a need to study and identify the forest policies, programmes and practices that contribute to vulnerability of forest ecosystems to climate change.

Adaptation should be rooted in addressing the climate-induced vulnerabilities that people face, particularly of poor people living in and around forests and watersheds. This can be achieved by a combination of structural and non-structural measures that reduce vulnerabilities and/ or increase the resilience of poor people. Adaptation approaches should consequently seek out win-win options whereby actions today will meet immediate needs and will also create the basis for reducing future vulnerabilities and the capacity for more effective adaptation as the impacts of climate change hits hard. These actions should include local-level ecosystem management and restoration activities that promote sustainable and alternative livelihood among poor communities.

There is need to diagnose existing policies and regulatory systems in relation to their effects on climate- induced vulnerabilities, including forests, forestry, disaster management, water and other pertinent services. That is required in order to develop a Climate Change Adaptation Strategy, involving requisite reform measures and investment options to enhance the resilience and reduce the vulnerability of the people to climate variability and change and enhance their access to ecosystem services. This should include both structural and non – structural measures, and the financial means and the institutional changes necessary to implement successful adaptation processes.

The Mekong region will have to adapt to inevitable climate change and assess the risks to economic growth and poverty reduction objectives. Climate change will profoundly affect people's livelihoods, forests and other natural resources, particularly fresh water, crop yields and fish stocks, and current infrastructure. Less predictable rainfall patterns will alter natural and agricultural ecosystems. Weather related natural disasters, such as droughts and floods, may become more severe and frequent. Poor and disadvantaged groups will be most vulnerable to these impacts.

Climate change and REDD related research in the region should be undertaken speedily through networking and collaborative programmes. This is to enable enhanced understanding of climate change impacts across sectors, contribute to informed policy making and effective strategies. There is a particular need to develop and implement national, regional and local strategies enabling vulnerable communities' adaptation to these impacts. This will support the mainstreaming of the predicted impacts of climate change into public expenditure, planning, programmes and regulations. These would include accessing carbon finance to support afforestation/reforestation with REDD at the forefront. It shall help build resilience to current climatic variability through better management and conservation of forests, land and water resources and access to a more diverse range of income generating opportunities, REDD and related carbon funds. There is a need to plan, manage and adapt to existing vulnerability, including climate risk and strengthening capacity to cope with current climate variability and future climate change. This will support more effective disaster preparedness and adaptation programmes.

Climate change resulting from increased greenhouse gas concentrations has the potential to harm societies and ecosystems. In particular, forestry, water resources, human health, coastal settlements, and natural ecosystems will need to adapt to a changing climate or face diminished functions. The changing climate patters, and especially the increased frequency and/ or severity of extreme events, will increase vulnerability to natural disasters, both slower onset ones such as drought and rapid onset disaster such as flood and cyclones. The poor and rural communities are more heavily dependent on ecosystem services, and are therefore most severely affected by deteriorating environmental conditions and factors limiting resource access. While, climate change is not only threat to natural resources and livelihoods, climate induced changes to resource flows will affect the viability of livelihoods unless effective measures are taken to protect and diversify them through adaptation.

Adaptation actions and strategies present a complementary approach to mitigation. While mitigation can be viewed as reducing the likelihood of adverse conditions, adaptation can be viewed as reducing the severity of many impacts if adverse conditions prevail. REDD and related mechanisms must envision this convergence and evolve accordingly as a concerted action programme for combating climate change and its impact.

REDD & REDD+ FAST FACTS

The "Little REDD Book" is a good guide on Reducing Emissions from Deforestation and Degradation (REDD), describing how REDD has evolved rapidly since it was introduced to UNFCCC in 2005. REDD is recognition of the significant role of forests in absorbing carbon dioxide, one of the greenhouse gases that cause global climate change. However, if trees are cut down, carbon goes into the atmosphere, adding to already harmful levels of atmospheric greenhouse gases. In order to

Total Portfolio $:	54,131,128
Total Commitments $:	54,587,496
Total Deposits $:	54,131,128
Approved for funding $:	37,443,095
Transfers to Part. Orgs $:	15,829,961
Participating agencies:	3
Number of donors:	2
Approved Projects:	6

Table 8.1: UN-REDD Programme Fund

address this, the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD Programme) was developed by FAO, UNDP and UNEP in response to the COP13 decision.

Under the REDD provisions, an estimated US$12 to $14 billion in government and corporate money will be dedicated to forest protection. A multi-donor trust fund was established in July 2008 that allows donors to pool resources and provides funding to activities towards this programme. The REDD goal has been to establish a functioning international REDD finance mechanism that can be included in an agreed post-2012 global climate change framework.

A functioning international REDD finance mechanism needs to be able to provide the appropriate revenue streams to the developing countries and pertinent people to make it worthwhile for them to shift to a sustainable forest management mode. The aim is to generate the requisite transfer flow of resources to significantly reduce global emissions from deforestation and forest degradation. Until recently, the UN-REDD Programme Portfolio Fund has been placed at around US $54 million, as indicated below.

Given the outcome of COP-15, REDD and REDD+ stand stronger, backed by more consensus and more references in the Copenhagen Accord than any other climate action. In the face of these heightened stakes, the UN-REDD Programme is poised to play an important role in climate change issues. Meanwhile, the UN-REDD Programme Policy Board has moved quickly to approve US$24 million in funding for nationally-led REDD+ processes, and another US$9.5 million for global programmes that provide support to national efforts. The Programme is now working with nine member countries in Africa, Asia and Latin America, and in October 2009, five more countries were given observer status, bringing the total number of countries involved in the UN-

REDD Programme to 14 in just over one year of operation. Countries such as the DRC, Indonesia, Tanzania and Viet Nam are now set to start implementing their projects. Nevertheless, the Programme must leverage new and additional streams of funding, which it is bound to arrange as also to further explore and highlight the co-benefits of REDD+ and fully demonstrate how it can benefit biodiversity and other ecosystems. A key priority should be to ensure even closer coordination between the UN-REDD Programme, the World Bank and other multilateral and bilateral initiatives supporting REDD+ efforts. The UN-REDD Programme and the Forest Carbon Partnership Facility, could be, "a starting point in the design of a unified and coherent institutional architecture for REDD+ to meet country requirements in a timely, effective and coordinated manner."

REDD projects cost an estimated $5 to $15 to eliminate each ton of carbon emissions, far less than it costs to, say, substitute solar panels for coal plants. They can also be done quickly, compared to, say, the time it takes to permit and build a nuclear plant. In order to contain the impacts of climate change within limits that society will reasonably be able to tolerate, the global average temperatures must be stabilized within two degrees Celsius. This will be practically impossible to achieve without reducing emissions from the forest sector, in addition to other mitigation actions. So REDD is urgent and important.

It is predicted that financial flows for greenhouse gas emission reductions from REDD could reach up to US$30 billion a year. This significant North-South flow of funds could reward a meaningful reduction of carbon emissions and could also support new, pro-poor development, help conserve biodiversity and secure vital ecosystem services. Further, maintaining forest ecosystems can contribute to increased resilience to climate change. To achieve these multiple benefits, REDD will require the full engagement and respect for the rights of Indigenous Peoples and other forest-dependent and related rural communities.

REDD “offers a rare partnership opportunity between two disparate and often conflicting worlds: capitalism and conservation. With REDD, you can “save the planet and make money” (Marshall, 2009). To “seal the deal” on climate change, REDD activities in developing countries must complement, not be a substitute for, deep cuts in developed countries’ emissions. The decision to include REDD in a post-Kyoto regime must not jeopardize the commitment of Annex I countries to reduce their own emissions. Both will be critical to successfully address climate change mitigation, adaptation and development (MAD).

Conclusion

While deforestation and forest degradation in developing countries is a major carbon emitter and driver of climate change, it also contributes to deepening of poverty and vulnerability of biodiversity rich ecosystems and local communities. They must be motivated through REDD and related PES and taken on board as informed partners along with other stakeholders of society concerned about the impact of deforestation and the urgency of implementing climate change adaptation and mitigation measures.

REDD - Reducing Emissions from Deforestation and Forest Degradation - is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forest lands and invest in low-carbon paths to sustainable development. REDD and REDD plus are thus an opportunity for combating climate change as well as for promoting SFM and environmental services with due financial and other co-benefits to the concerned countries and communities for delivering much needed climate change mitigation, adaptation and development mechanisms.

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9

CLIMATE CHANGE - POTENTIAL AND CHALLENGES TO MEKONG RIVER BASIN DEVELOPMENT AND COOPERATION

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ABSTRACT

According to primary analysis, a projected temperature rise of 2.5°C-4.5°C by 2070 will cause the amount of Mekong flow in Vietnam to vary due to the change in rainfall. Flow will reduce by 10% to 30% with a reduction of 10% in rainfall. Significant changes will likely occur in south of Central Vietnam and in the south-eastern region. Especially, during the dry season, the flow will reduce by 10%-15% if rainfall declines by 10% and temperature increases by over 1.5°C. With sea water level likely to rise from 0.3 to 1.0 meter, more damages will occur to the Mekong River and Red River deltas and central coastal zones. Annual rainfall distribution has changed significantly and becomes concentrated to some wet season months. Rainy season could finish 1 month earlier. In the dry season or winter-spring period, there have been long spells with no or very small amount of rainfall.

Global climate change is having a strong effect on water resources. The most recent IPCC analysis indicates:

- The timing and regional patterns of precipitation will change, and more intense precipitation days are likely to increase;
- Precipitation is expected to increase in higher latitudes, particularly in winter;
- Potential evapotranspiration (ET) rises with air temperature. Consequently, even in areas with increased precipitation, higher ET rates may lead to reduced run-off;
- More annual run-off caused by increased precipitation is likely in the high latitude areas. In contrast, some lower latitude basins may experience large reductions in run-off and increased water shortages as a result of a combination of increased evaporation and decreased precipitation;

- Flood frequencies are likely to increase in many areas. Frequency and severity of droughts could increase in some areas as a result of a decrease in total rainfall, more frequent dry spells, and higher ET;
- Hydrology of arid and semiarid areas is particularly sensitive to climate variations. Relatively small changes in temperature and precipitation in these areas could result in large percentage changes in run-off, increasing the likelihood and severity of droughts and/or floods;
- Water quality problems may increase where there is less flow to dilute contaminants introduced from natural and human sources.

The Mekong River is one of Asia's great rivers: it is 4,800 km long with a catchment area of 795,000km². It flows through six countries (China, Myanmar, Thailand, Laos, Cambodia and Vietnam), incorporates a massive lake system and downstream of Phnom Penh fans, it out into a series of channels before discharging into the Sea. The Mekong River Basin is divided into two sub-catchments, i.e., the Upper Mekong River Basin, including China and Myanmar; and the Lower Mekong River Basin considered as the area downstream of Laos and Thailand, contributing about 77% to total catchment area.

More than 60 million people live in the Lower Mekong River Basin, and millions of them rely on the river system's resources as primary sources of nutrition and income. The development of the river's natural resources for domestic uses, hydropower, navigation, and irrigation is key to poverty reduction and welfare improvement. Thus, a decline in water volume or changes in flow regime may affect livelihoods and food security of millions of people in the region. Agriculture, aquaculture, navigation, and water supplies for household, commercial and industrial use could be affected by changes in water levels. Climate change, particularly sea level rise, poses a threat to the basin. Analysis shows that 15,000km², or about 38% of its area would be inundated with sea level rising about 0.75m.

INTRODUCTION

The impacts of climate change will affect everyone. Some have calculated that the costs associated with overcoming climate impacts could even exceed global economic output within a few generations. Despite contributing least to global warming, poor people will be hit first and hardest by climate change. For instance, they're often forced to live in temporary settlements, on land prone to flooding, storms and landslides.

Vietnam is likely to be among the countries hardest hit by rising sea levels, according to a World Bank research, which warned that the country's Mekong delta would be among those areas under most serious threats of 'disappearing' caused by sea level rise.

The Mekong River, originates in the Qinhhai-Tibetan in China and ends in the Ca Mau Peninsula of Vietnam, with a total catchment area of 795,000 km^2. Across its extent, the catchment varies dramatically including a vast array of regional ecosystems, including; alpine plateaus, tropical forests, mountainous highlands, mangroves, coastal wetlands, floodplain forest and arid grasslands. It is home to some 60 million people of 100 ethinic groups and is a key region for the economies of Thailand, Vietnam, Laos and Cambodia, as well as an important site of biodiversity in Southeast Asia.

The delta comprises 5.5 million ha, and is generally denoted as the area downstream of Phnom Penh with about 1.6 million in Cambodia and 3.9 million in Vietnam. The deltaic regions' low-relief has proven more suitable for agriculture and human habitation, consequently the Mekong Delta is the most developed region of the MRB supporting the greatest population densities. Ground levels range between 0.7-1.2m above sea level, except in the vicinity of the Cambodian border where elevations are approximately 2.0-4.0 m including some small mountains in An Giang province.

The part of the Mekong Delta within Vietnam (known as the Cuu Long delta consists of 13 provinces, accounting for 12.1% of Vietnam's land area with approximately 18 million inhabitants. The delta has become the 'rice bowl' of Vietnam, contributing 50% to the nation's food production, including 95% of rice exports, 65% of fisheries production and 70% of fruit.

The delta was highlighted in recent IPCC, UN and World Bank reports as an area of particular concern because of the potentially devastating effects climate change could bring in the coming decades. The region, already prone to frequent and large-scale flooding, sea water intrusion and contaminated soil, is projected to be the most seriously inundated.

The Government of Vietnam has taken early actions to respond to climate change and its impacts as it early ratified the United Nation Framework Convention on Climate Change and the Kyoto Protocol let alone a series of sector assessments made and adaptation options identified.

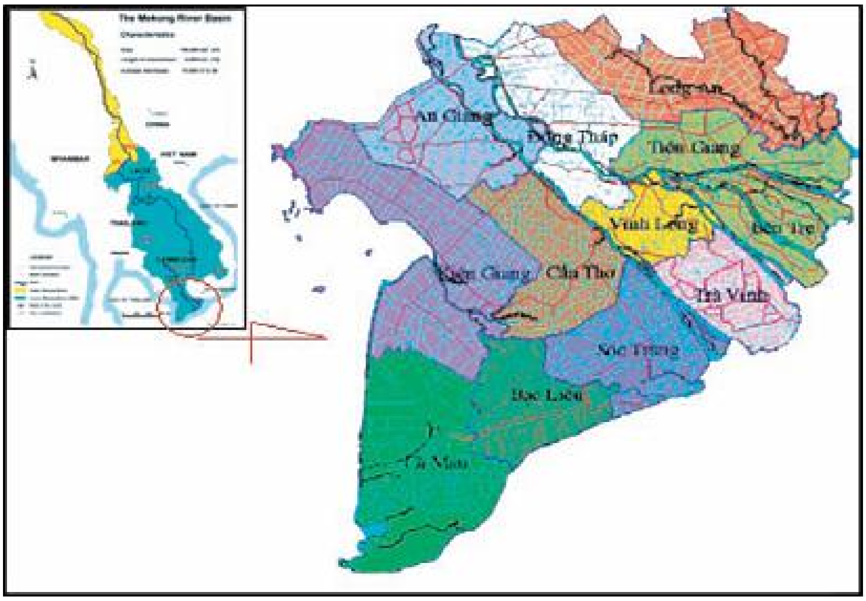

Figure 9.1: The Lower Mekong River Basin

There are concerns, however, that measures taken in one locality of the Mekong river basin may have significant 'spillover' effects on neighboring or downstream communities. In this context, the potential for unintended consequences of these actions, should be explored including options for reducing negative effects, and options for collective actions that may increase the effectiveness and positive effects of the adaptation measures .

overview of impacts of climate change on the mekong river basin

According to the World Bank report (2007), Vietnam is among the countries which are hardest hit by climate change and sea level rise, with the Mekong and Red River deltas projected most seriously inundated. With a 1 meter sea level rise, about 10 % of the population would be directly affected and GDP loss may rise to 10%. About 40,000 km^2 of the coastal deltas are inundated every year, in which, about 80% of the Mekong River delta is almost completely inundated. Sectors, areas, and localities vulnerable to climate change are identified as water resources, agriculture and food security, public health, deltas and coastal areas.

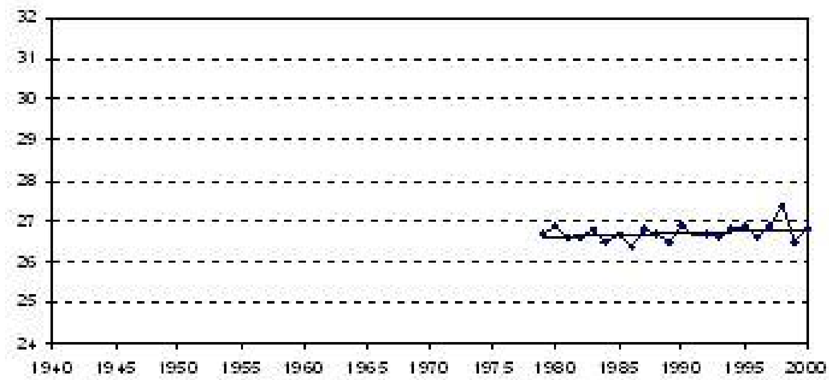

Figure 9.2: Change in Annual Average Temperature at Can Tho Station

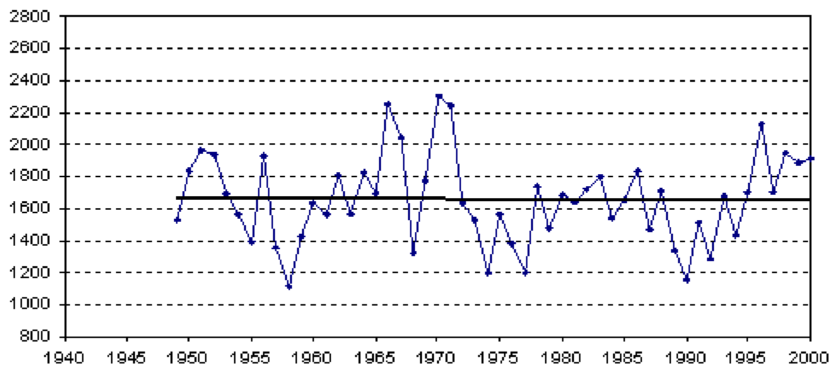

Figure 9.3: Change in Annual rainfall at Can Tho station

Impacts of Climatic Extremes

The increase of climatic extremes in both frequency and intensity due to climate change poses frequent threats, both short-term and long-term, to all sectors and communities. Under the impacts of climate change, natural disasters, such as storms, floods, droughts, heavy rains, and heat spells will be much fiercer, causing huge damage to production and life in country in general and the Mekong delta in particular. These catastrophes threaten the region's socio-economic development and may undo many years of development as the delta is expected to suffer serious impacts of those extremes.

The delta, however, will also benefit from floods, which make soil more fertile, resulting in higher rice yields and an increase in natural fish stock. Also, floods can kill certain crop pests and viruses.

Impacts on Water Resources

Water resources, one of the most vulnerable factors to the change of weather and climate, are under higher pressure due to increased droughts, which will affect directly agricultural and industrial production, water supply for rural and urban areas.

According to some recent research, climate change will influence characteristics of flow including total flow volume, frequency of the extreme events (drought and flood), seasonal regime, salinity intrusion and water quality in the ongoing decades. Thus, it is necessary to have plans and measures to adapt effectively to the climate change and it is important to determine impacts of climate change on water resources.

The Mekong delta is located downstream of a major international river with annual water run-off 505 billion m^3 to the sea. Therefore, any change in the hydrological regime will make remarkable change in water resources management.

The spatial and temporal distribution of run-off is very uneven as over 80% of run-off is in 5-6 wet months and about 20% in 6-7 dry months.

Sea level rise, in combination with the increase of rainfall in the rainy season, will seriously impact low coastal zones, particularly the Mekong delta, where 85% of total inundation will affect 12 provinces and cover 12,376 km^2. More than 1,100 km^2 will be inundated in the South-Eastern economic region(7.65% of the total inundated area).

Location	Annual run-off m^3/s			Low flow m^3/s			Flood-top discharge m^3/s		
- River	At present	In 2070	%	At present	In 2070	%	At present	In 2070	%
Mekong River at Pakse									
- Case 1	1020	10645	+4.2	1723	1686	-2.0	148.000	171,000	+15,0
- Case 2		8701	- 15.0		1443	- 16.2		176,000	+19,0
- Case 3		8645	- 15.3		1312	- 24.0		137,000	-7,0

Table 9.1: Run-off change in the Mekong Rivers by 2070
Source: Vietnam Initial Communication to UNFCCC, MONRE, 2003

Economic Region	Province	Inundated area (sq.km)	% of SLR area	% of province area	% of total land area*
Mekong River Delta	An Giang	192.3	1.32	5.45	0.06
	Bac Lieu	961.9	6.62	38.87	0.29
	Ben Tre	1,131.4	7.79	50.14	0.34
	Ca Mau	1,182.8	8.14	22.75	0.36
	Can Tho	757.7	5.22	24.75	0.23
	Dong Thap	389.4	2.68	11.53	0.12
	Kien Giang	1,756.8	12.09	28.22	0.53
	Long An	2,168.9	14.93	49.42	0.66
	Soc Trang	1,424.6	9.81	43.71	0.43
	Tien Giang	783.2	5.39	32.68	0.24
	Tra Vinh	1,021.3	7.03	45.72	0.31
	Vinh Long	606.4	4.17	39.69	0.18
Mekong River Delta Total		12,376.7	85.19	31.00	3.76

Table 9.2: Area inundated by 1 meter sea level rise in Mekong delta
Source: Jeremy Carew-Reid, International Centre for Environmental Management, Feb, 2008

Impacts on Crop Distribution

Due to global warming, the planting boundary of tropical trees/crops will move towards higher latitudes. On the other hand, the adaptation area of subtropical plants would become narrower. By the 2070s, mountainous tropical trees will be able to grow at the altitude 100-550 metres higher and move 100-200km northwards in comparison with present.

Significant cultivation areas in the Mekong delta will be under salt water due to sea level rise.

The rice crop in the Mekong delta was damaged on a large scale in 2000, but much less so in 2001 as shown in table 9.3.

Table 9.3: Rice Crop Damage in Mekong Delta

	2000	2001
Lost rice area (ha)	55,123	4,553
Submerged rice fields with reduced yield (ha)	159,360	53,267

Assessments by authorities show that damage to fruit and fish cultivation was also greatly reduced from 2000 to 2001 as shown in table 9.4.

Table 9.4: Fruits and Fish Cultivation Damage

	2000	2001
Lost fruit trees (ha)	59,626	20,983
Lost industrial trees (ha)	23,025	10,148
Lost fish ponds (ha)	14,045	5,588

SEA START RC (2006) found that the Mekong delta's rice production may be severely impacted by climate change, particularly in the summer-autumn crop, which may see yields reduce by over 40% [5].

Impacts on Forest Ecosystem

Climate change with increasing temperature, change of rainfall and sea level rise would affect forest coverage and ecology in various aspects.

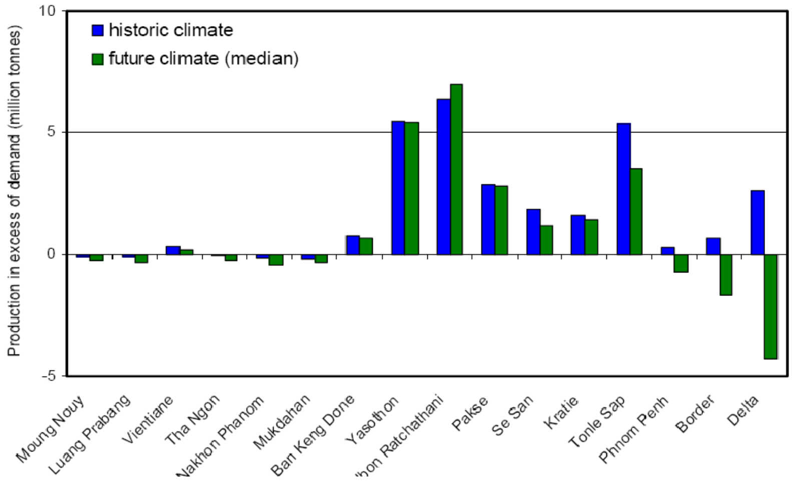

Figure 9.4: Historical (1951-2000) and future (2030) production in excess of demand

The forestry sector's vulnerability becomes more pronounced under high sea level rise, which would result in a decline of mangrove forests in the delta, affecting adversely indigo forests and forest planted on the region's sulfated soil.

Increasing temperature in combination with abundant solar radiation would promote the photosynthesis process that leads to the acceleration of assimilation of verdurous trees. However, due to the increase of evapotranspiration, soil moisture will reduce and the biomass growth index of forests will decline. The increase of temperature and droughts would lead to increased threat of forest fires, and plant pests and diseases.

Impacts on Aquatic Eco-system

Salinity intrusion due to sea level rise may lead to following consequences:

Habitat of fresh water creatures will get smaller due to the occupation of sea water.

Mangrove forests would reduce and ecosystem of some aqua-cultural species will be affected.

The fixing-organic-matter capacity of seaweed ecological system will fall as a result of decreasing sources of photosynthesis products and nutrition for living creatures in sea- and river-beds. Thus, quality of living habitat of various aqua-creatures will get worsen.

The increase of water temperature will lead to clearer thermal vertical stratification that, in turn, would affect biological habit of living creatures.

With increasing temperature, some species would dive to deeper depths, changing the vertical distribution structure of aqua-creatures.

Increasing temperature will also accelerate mineralization and organic decomposition processes and affect the food system of living creatures. Cold blooded living creatures consume more energy for respiration, leaving less energy for other living activities which can reduce the productivity and commercial quality of aqua-cultural products of the delta.

Increasing temperature will cause the degeneration or destruction of coral reef and change the physiological, bio-chemical processes occurring during the interaction between coral reef and algea.

Due to high rainfall intensity, salt concentration of seawater would reduce by 10-20% during long periods (from some days to weeks). As a result, brackish water and coastal living creatures, especially, bivalve mollusks (e.g, arca and oyster) would die en masse as they are not able to stand against changes in salt concentration.

Impacts on Income from Sea products and Fisheries

Due to sea level rise, hydro-physical, hydro-biological and hydro-chemical regimes of the river will degrade. As a result, the existing coenosium would change its structure and components and supplemental reserve would be seriously reduced. The region's sea products would fall at least one third in comparison to the present.

Due to increasing temperature, the distribution of resources would be more dispersed with the number of tropical fish of low commercial value, except tuna, increasing and the number of fish of high commercial value decreasing or even disappearing. Most coral reef fish would vanish.

Phyto plankton, the first link of the food chain for plankton and juvenile fish would be destroyed leading to sharp decreases of plankton - the main food source for animals in the middle and above layers. The following consequences may occur:

- Migration of fishes to other areas (passive migration);
- Reduction of body weight of fish.

Impacts on Energy, Transportation Sectors

The Mekong river's run-off regimes would change, thus obviously affecting local water regulation mechanisms. Sea level rise and heavy rainfall would inundate lowlands, and cause flash floods, landslides as well as the destruction of dams and hydro-electric power facilities. This will result in increased expenditures on the drainage of water and the maintenance of dykes and dams, as well as hydro-electric power facilities.

Increasing temperatures will also result in higher energy consumption for cooling purposes, particular commercial and industrial facilities.

Changed characteristics of the typhoon season will directly affect the energy sector, threatening existing infrastructure for oil and gas exploitation and transportation, and electricity transmission and distribution systems.

Impacts on Industry and Construction

As part of the southern major economic hub, the Mekong delta hosts major industrial parks, which are located in low-lying coastal areas. These areas face great threats from floods and inundation from sea level rise. Thorough assessments of the challenges caused by sea level rise should be made for existing facilities and for the design and construction of future parks.

The supply of water and materials for construction and industrial production would become more difficult under the impact of climate change. Moreover, frequent extreme events and disasters would negatively affect the quality and lifetime of materials, machines and equipment, and buildings, adding higher maintenance costs.

Therefore, climate change issues should be taken into account while reviewing existing plans of industry and the construction sector in the region. Also, technical standards should be developed for the sector to effectively adapt to and mitigate impacts of climate change.

Impacts on Culture, Sports, Tourism, Trade and Service

The region is a famous centre of culture, tourism, sport, trade and services. However, future development of the region's culture, sport, tourism, trade and services would be under threat from climate change.

Economic Region	Province	Number of people affected	Total population of province	People affected as percent of total population of province	People affected as percent of total population within SLR inundation zone
Mekong River Delta	An Giang	197,085	2,372,860	8.3	3.36
	Bac Lieu	383,764	857,521	44.8	6.54
	Ben Tre	759,174	1,389,730	54.6	12.94
	Ca Mau	182,956	1,206,390	15.2	3.12
	Can Tho	426,511	2,046,210	20.8	7.27
	Dong Thap	222,289	1,662,590	13.4	3.79
	Kien Giang	295,989	1,590,910	18.6	5.04
	Long An	581,456	1,488,070	39.1	9.91
	Soc Trang	457,821	1,307,200	35.0	7.80
	Tien Giang	497,075	1,728,190	28.8	8.47
	Tra Vinh	418,066	1,101,850	37.9	7.12
	Vinh Long	364,414	1,152,190	31.6	6.21
Mekong River Delta Total		4,786,600	17,903,711	26.7	81.56

Table 9.5: Population affected by 1 metre sea level rise inundation
Source: Jeremy Carew-Reid, International Centre for Environmental Management, Feb,2008

Under the impact of sea level rise, many beautiful beaches, natural landscapes, historical and heritage sites, and tourist attractions will disappear or become damaged.

At the same time, climate change with sea level rise and increasing temperature would promote the spread of epidemics, which may negatively effect tourism and other cultural and sports activities, resulting in a decrease in the number of tourists in the region.

Impacts on Population

Impacts by sea level rise will affect over 4.7 of the 18 million people in the Mekong delta, which accounts for 82% of the total number of affected people in Vietnam. With a 1 metre sea level rise, six of 12 Mekong delta provinces will have over 30% of their population affected. Ben Tre and Bac Lieu provinces are projected to be hardest hit with 55% and 45% of their respective population affected.

Floods caused by sea level rise and storm surges have caused huge losses to local people, especially the poor, who are particularly vulnerable due to their shortage of resources to recover floods and other natural disasters.

The delta's flood prone localities include An Giang, Dong Thap, Long An, Can Tho, Tien Giang, Kien Giang, and Vinh Long. In 2002, floods submerged 85% of the total area of Dong Thap Province; 70% of Long An Province; and 60% of An Giang Province, all in the lower reaches of the Mekong Delta.

Impacts on Human Health

Increasing temperature would have adverse impacts on human health, particularly elderly people or people with cardiac diseases and mental disorder. A change in climate would result in changes of seasonal structure, thus leading to changes in biological rhythm.

Also, increasing temperature will help disease carriers spread quickly. It will facilitate the growth and development of various viruses and insects. Therefore, infectious diseases as malaria, synaptic filariasis, dengue fever, Japanese encephalitis and arboviral diseases are considered to be common in humid tropical regions like the Mekong delta.

Impacts on Coastal Zone

The impacts of sea level rise on coastal zone are assessed based on the scenario of a 1 metre sea level rise by 2100 as follows:

- A 1 metre sea level rise will seriously inundate the Mekong delta with Ca Mau, Tra Vinh, Soc Trang, Ba Ria - Vung Tau provinces, Ho Chi Minh City most seriously affected.
- The region's coastal community will suffer from annual flood and inundation.

Impacts of Sea Level Rise on Mangrove

Sea level rise might put a large number of the delta's existing forests under water. Climate change will also result in a change in the characteristics and structures of mangroves. The increasing hot and dry weather would adversely affect the growth and development of mangrove forests.

Impacts of Sea Level Rise on Planning of Residential Areas and Construction

Due to sea level rise, the land area available for the planning of residential and urban areas would become narrower. At the same time, storm surge will become stronger, threatening structures in the area's low-lying lands.

In addition, sea level rise would threaten existing industrial, transport and defence infrastructure facilities designed and built in accordance with present sea level. The increase of flood and inundation would negatively affect the foundations of structures while the increase of

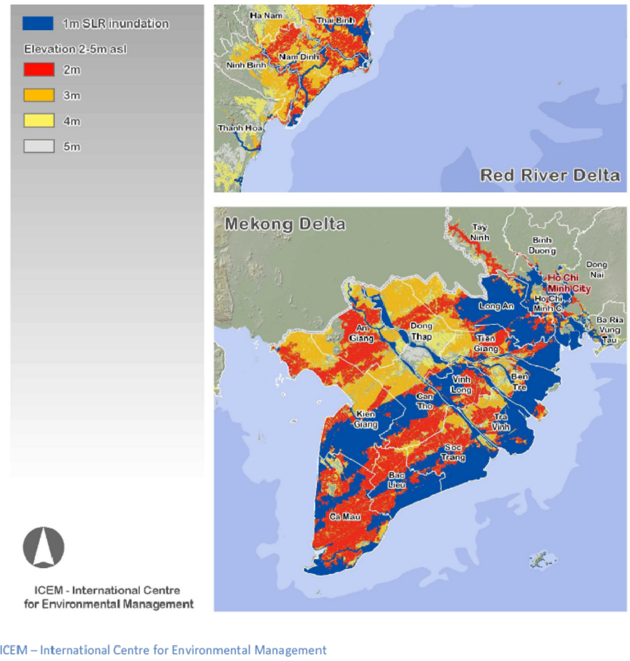

Figure 9.5: Sea level rise 1m inundation area
Source: Jeremy Carew-Reid, International Centre for Environmental Management, Feb, 2008

	Climate change and disaster impacts
Short-term	• More severe typhoons will strike Vietnam, leading to large-scale losses of life and agricultural, fisheries production in coastal areas • More floods and inundation will occur with higher severity, negatively impacting on people's production in mountainous and delta areas.
Medium-term	• Climate change and related disasters would lead to outbreaks and spread of known and new diseases • Increasing temperature, desertification, sea level rise and salinity intrusion will affect the availability and quality of surface and ground water
Long-term	• Due to sea level rise, several areas are likely to 'disappear' under the sea • Large-scale desertification would lead to great losses of land available for cultivation and aquaculture • Increasing temperature would lead to changes in eco-systems and difficulties for agricultural and fisheries production

Table 9.6: Climate change and disaster impacts assessment in Vietnam

typhoons and tornadoes would require the strengthening of structures at higher costs.

Capacity for climate change adaptation in the Lower Mekong River Basin

The Government of Vietnam, with a clear vision on climate change impacts, took early action, ratifying the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 and Kyoto Protocol in 2002. In 2008, the Prime Minister of Vietnam signed a decision to approve the National Target Program to Respond to Climate Change. Moreover, many programmes and projects have been implemented at the national and local levels.

For the Mekong delta, some strategies, programmes and projects have been developed to reduce risks of potential impacts of climate change. However, the strategies, programmes and projects have so far only focused on short-term responses to climate extremes, rather than long-term measures to respond to future climate change. Furthermore, climate change has yet to be integrated into the planning of socio-economic development in the region.

The development and implementation of climate change initiatives in the region face the following difficulties, including the lack of knowledge on climate change and its impacts among local communities and some governmental agencies, and the shortage of human resources, the lack of technical and financial support.

Even though the Government approved the NTP to Respond to Climate Change, there are still difficulties to its implementation. Concretely:

FIRSTLY, poor awareness about climate change and measures to respond to it among decision-makers, officials at all levels as well as social organisations and local communities. Therefore, raising awareness at all levels is a first priority.

SECONDLY, the lack of coordination among stakeholders in taking actions against climate change issues, which have yet to be integrated into the development of policies, and plans on socio-economic development of sectors, agencies and localities.

THIRDLY, the lack of tools, guides for decision makers and experts in sectors, and communities. Therefore, training and knowledge upgrading; collecting and utilizing the data on climate change; developing tools/methodologies for analysis and adaptation to climate change, are important activities that should be done immediately.

FOURTH, limited knowledge. Climate change is a long-term issue and its impacts are very complex. However, knowledge about climate change and its impacts on the earth and Vietnam is still limited.

NEEDS TO OVERCOME LIMITATIONS

Developing countries do not have the resources to finance national adaptation - and should not be expected to cover the costs alone. Many developing countries are the most vulnerable to climate impacts, yet have had the least role in causing the problem. Oxfam estimates that adaptation in all developing countries will cost at least $50bn annually, and far more if greenhouse gas emissions are not reduced fast enough to keep global warming well below 2°C [41]. International adaptation finance will be needed to enable a wide range of measures, from community-led initiatives and disaster risk reduction strategies to long-term national planning and social protection in the face of unavoidable impacts.

To improve on this requires strengthened communication, and comprehensive research on the possible impacts of climate change on the Vietnamese economy and key development goals, particularly poverty reduction. And little is known yet on the potential social and economic implications of, for example, sea level rise on settlements and agriculture, or changes in climate conditions that could result in significant numbers of 'climate refugees'. Research is needed on the most effective long-term adaptation measures and strategies to ensure human well-being and continued economic growth and poverty reduction.

A facility for information-sharing and for defining and sharing of lessons is needed so that others can benefit from agencies with experience in integrating climate change adaptation into their socio-economic planning.

Coordination between line ministries also needs to be urgently improved, and cooperation with international agencies and NGOs enhanced so that climate change can be addressed in an integrated way with long-term socio-economic and poverty reduction efforts.

The idea of a high-level coordinating body should be explored with authority to set policy and provide cross-sectoral direction and coordination. The Government might consider establishing a high-level, cross-ministerial, national climate change coordination platform [4].

In order to facilitate adaptation planning and piloting, guidelines are needed for line ministries such as MPI, MARD and MOC showing how to integrate climate change into their development planning processes. Key sectors and local government will need strong technical support in vulnerability analysis and adaptive planning.

Need for translation of the scientific studies results to the language of the end-users. One of the most difficult but important tasks is to translate the scientific results to the easy-to-understand language for the different target groups: the provincial leaders and policy makers, the sectoral managers and local authority; the local communities and poor people. Local people do not talk in the same language as the experts, and often cannot understand scientific issues, so all results should be simplified and correlated with local/regional customs and problems.

conclusions and recommendations

Vietnam is likely to be hardest hit by rising sea levels. The Mekong delta in Vietnam will be among those areas under most serious threat of 'disappearing', caused by sea-level rise. With a 1 metre sea level rise, about 10 % of the population will be directly affected and GDP will decrease by 10% with about 40,000 km² of the coastal deltas inundated every year and 80% of the Mekong delta almost completely inundated. Natural disasters have become increasingly serious in Vietnam. Drought, typhoons and tropical storms are getting more severe; huge floods, repeated floods have occurred recently.

Despite many difficulties and challenges, the NTP to Respond to Climate Change has helped integrate climate change issues into socio-economic development plans and strategies at all levels.

To implement the NTP effectively in Vietnam in general, and in the Mekong delta in particular, it is necessary to develop comprehensive initiatives, programmes and projects on capacity building for sectors and local communities, so as to help them develop effective measures to respond to climate change impacts. Additionally, cross-sectoral and inter-sectoral co-operation and co-ordination should be promoted among local authorities, agencies and communities and awareness improvement should a priority. More concretely:

firstly, capacity building should be promoted at the national level to implement the NTP in the Mekong delta. To date, there have been no systematic mechanisms on the implementation of adaptation measures among different ministries and tools and methodologies to be used. It is necessary to start with a basic knowledge on climate change and climate change impacts assessments.

secondly, institutional assessment should be conducted with the participation of relevant stakeholders in order to assess the capacity for the implementation of adaptation policies and the determine capacity building requirements and policy support/changes required to implement adaptation policies.

third, sector-specific climate risk and vulnerability information package should be developed to provide guides on the implementation of adaptation policies. The package for the Mekong basin should include information about climate behaviour in the past, the present and the future. This, in conjunction with stakeholder consultations, will help ensure that adaptation interventions will be appropriate and cost-effective. The Synthesis of climate information from climate change studies should be conducted for the whole basin and inputted into a database which can be shared for the whole basin. The package of climate risk information should be developed in a format that is operationally usable and understandable.

FOURTH, climate risk information application manuals should be developed for guiding the development of action plans that contain specific adaptation targets. The manuals will provide a step-wise practical guidelines to enable the lead agencies and local agencies to analyze climate risk and adaptation. The manual could be used in replicating this capacity to implement adaptation targets in other provinces and districts.

FIFTH, a training curriculum will be developed for strengthening capacity of localities so as to help them develop specific adaptation targets within the initiative framework using science-based climate risk information.

SIXTH, workshop/ forums on the development of adaptation policy should be held with the participation of representatives from riparian countries.

SEVENTH, analysis should be sharpened via information sharing on similar efforts to set and implement adaptation policies in other countries, and learning from the experiences of others, specifically through: Sharing insights and ideas related to methodologies and tools; Attending regional and international meetings to disseminate information on initiative plans and results.

EIGHTH, the implementation of NTP in high risk-sites should be demonstrated. High-risk provinces in the Mekong delta, representing mangrove, wetland forestry and agriculture, lowland agriculture, and lowland aquaculture, fisheries, tourism and industry ecosystems that are at risk to climate-related hazards such as drought, flooding, typhoon, salinity intrusion, and sea level rise, will be selected to serve as demonstration sites for the development action plans for adaptation in framework of the NTP implementation. A livelihood adaptation approach will be adopted to take into account the impacts of climate risks to environment. The potential impacts of and vulnerability to climate change of the demonstration sites will be assessed by technical experts from MRC in consultation with members of the national, provincial and district experts. The assessment will combine science-based information with societal vulnerabilities. The assessment will give a full understanding of 1) where they stand today with respect to vulnerability to climate risks; 2) what factors determine their current vulnerability; and 3) how successful their efforts are to adapt to current climate risks; 4) what is their capacity to adapt to future climate risks; and 5) adaptation deficits.

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10

SPATIAL DATA SHARING FOR TRANSBOUNDARY BASINS: CATERING FOR CLIMATE AND ECOSYSTEMS CHANGE ADAPTATION

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ABSTRACT

In order to ensure basin-wide cooperation and development within international river basins, it is essential to have a common basin-wide dataset that can be readily used by all. This study demonstrates the value of utilizing basin-wide common spatial datasets and data sharing systems, using the Mekong River Basin as a case study. Also discussed is how spatial data sharing can be improved to enhance countries' responsiveness and adaptation to climate and ecosystems change, and to address transboundary issues. To understand the current situation with regard to spatial datasets, we conducted the following: 1) an expert needs questionnaire; 2) survey of available spatial datasets on the web; 3) survey of common datasets in global environmental assessments. A spatial data sharing system was then designed as a proto-type through which to analyze the trend of new technologies and clarify system requirements.

Key words: upstream and downstream, spatial- temporal scale, next generation of data sharing, open accessible, uncertainties, wiki, transboundary waters, international river basins, adaptation, climate change

INTRODUCTION

In order to ensure basin-wide cooperation and development within international river basins, it is essential to have common understanding on current and future environmental conditions and problems occurring in the basins. A key component to achieve this is to have a common basin-wide dataset that can be readily used by all. However, available global datasets covering an entire basin are often limited, and regional and local datasets are not always consistent on the spatial scale, time scale and categorization rules. In addition, current conventional datasets and data sharing systems are not enough to address climate and ecosystem change adaptation, in terms of its flexibility and dynamics for responding to rapid changes. Creating basin-wide common datasets, establishing systems to enable widespread sharing of such datasets, and ensuring that such datasets are responsive to rapid environmental changes, are all urgent and important issues for promoting basin-wide collaboration. Presently however, sufficient action has not been taken to address these issues in many river basins in the world.

The purpose of this study is to demonstrate the value of utilizing basin-wide common datasets and its sharing system, using the Mekong River Basin as a case study. Availability of basin-wide common datasets requires an update and clarification of existing available data, as well as an assessment of future data needs. Also, greater clarification is required on how to improve data sharing to enhance countries' responsiveness and adaptation to climate and ecosystems change, and address transboundary issues; challenges which require different datasets than the general data sharing system. Figure 10.1 shows the framework and methodology of this research. Firstly, we conducted interviews and field surveys to demonstrate current available spatial datasets on the Mekong, at basin-wide, regional and local scales. Next we conducted a literature survey of global environmental assessments such as the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report: Climate Change 2007, Millennium Ecosystem Assessment (2005), and United Nations World Water Development Report (2009), to illustrate existing common datasets used for climate and ecosystem change assessment and adaptation. By comparing these results, we can clarify what common datasets are needed and requirements for the Mekong. Secondly, the proposed data sharing system and its requirements was explored by comparing and analyzing existing state-of-the-art spatial data sharing projects for disaster response and environmental management. We consider the Haiti earthquake disaster response as the frontier project for spatial data sharing among various international disciplines. We analyzed it in detail to learn the lessons from this experience in order to apply it to the case of transboundary basins. Some concepts of "next generation data sharing" systems such as wiki-based open accessible platforms are also incorporated in the design of a system for the Mekong.

We hope that our results can contribute to promoting basin-wide scientific investigation and collaboration. Ultimately, we hope that

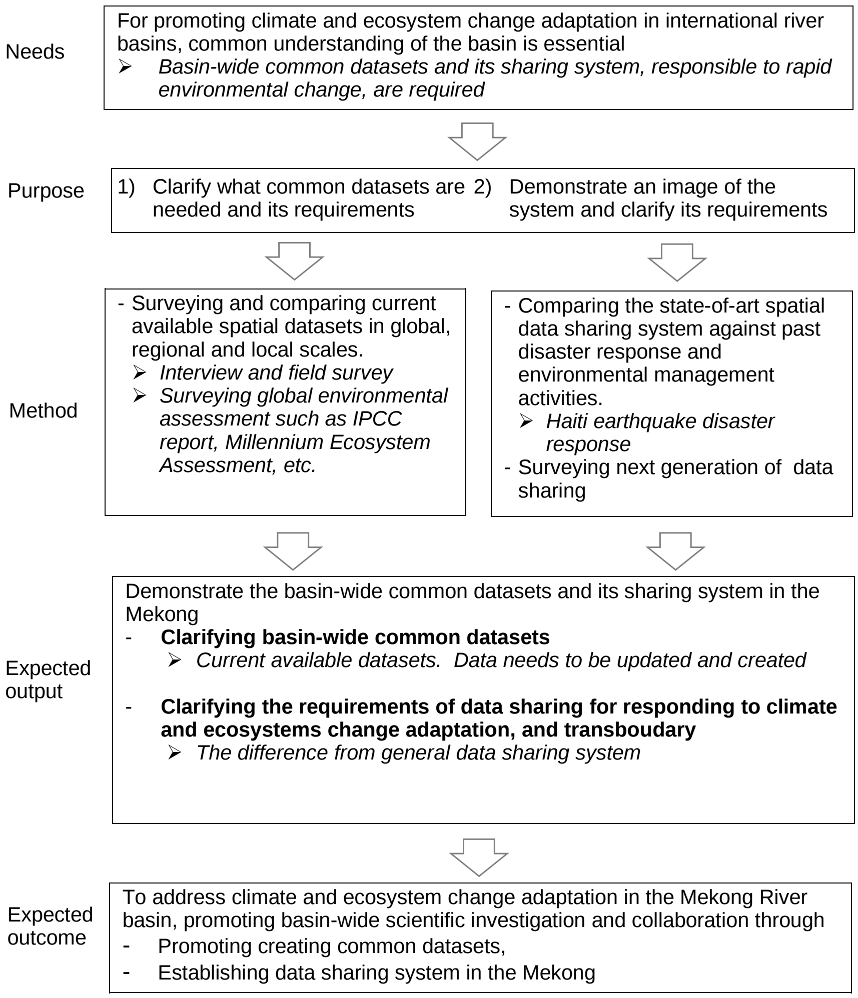

Figure 10.1: Total image of this research

through the creation of common datasets and establishing data sharing system for transboundary basin, this study can address climate and ecosystem change adaptation in the Mekong River Basin.

Surveying current situations of spatial dataset availability in the Mekong

Interviews and field surveys were conducted to demonstrate current available spatial datasets in basin-wide, regional and each country scales for the Mekong. Through a literature survey of global environmental assessments, such as the IPCC Fourth Assessment Report: Climate Change 2007, Millennium Ecosystem Assessment (2005), and UN World Water Development Report (2009), common datasets used for climate and ecosystem change assessment and adaptation are discussed. By comparing these results, we could investigate which common datasets are needed for the Mekong, and the requirements for experts to collaboratively obtain, share, manage and disseminate such datasets.

Expert needs questionnaire

To understand the needs of experts such as researchers and decision makers who are researching and working on the development of the Mekong, a questionnaire survey was conducted at the International workshop on "Climate Change Response for Asia International Rivers: Opportunities and Challenges", held in Beijing, China in February 2010. Among 35 participants from 9 countries were collected, covering 21 answers from various disciplines. Responder's areas of interest are as follows: Water resources (13); Ecosystem (11); Flood (10); Hydrology (9); Adaptation (9); Other (6). The numbers marked in parenthesis reflect the number of responders.

Two initial questions were asked to determine how experts currently utilize spatial data and their needs. The latter two questions asked their views on the future of spatial data sharing in the Mekong.

Regarding participants' current concerns or barriers to using shared spatial datasets on the internet, answers received on the multiple-choice were: "Difficulty in searching suitable data (11)" and "Data format conversion (10)" as the top two concerns by experts, followed by "Lack of sufficient data description/metadata (9)", "Credibility of datasets (8)", "Difficulty to process data for analysis/visualization (5)", "Slow Internet access (1)", "Insufficient spatial resolution (1)" and "I don't use

Category	Spatial extent	Attribute	Data format	Resolution	Num. of answers
Land-use/Land-cover	Entire basin Lower Mekong Cambodia	Land-use type, Land cover change, Rainfed, Irrigated craps	Grid Polygon	250m AHAP 1:50,000	16
Meteorological - hydrological observation data	Laos, Cambodia Entire basin Cambodia-Vietnam South East Asia	Rainfall, streamflow, temperature Water level	Point	AHAP	15
Soil	Entire basin Lower Mekong	Soil-type, infiltration rate, soil depth	Polygon Grid	1:50,000 200m AHAP	10
Forest cover map (Vegetation / NDVI)	Entire basin Cambodia	Forest type, biomass	Polygon	100m 1:50,000	4
Digital Terrain Model Digital Elevation Model	Entire basin	Elevation	Grid	10m AHAP	2
Other					5

Table 10.1: The expert's need for spatial data for promoting their own research or work

such spatial data (1)". Even though web search engines such as Google or Yahoo are quickly evolving, finding suitable datasets always seems difficult for experts.

Regarding responders' data needs for conducting research/work in terms of availability of spatial datasets, table 10.1 shows that land-use/land-cover, metrological-hydrological observation datasets, followed by soil, are high in demand.

Subsequently, we asked experts' opinions on what spatial datasets should be created as a common dataset for promoting basin-wide climate and ecosystem change adaptation in the Mekong. Responders were asked to select the top three they considered as essential. Similar to 10.1, table 10.2 shows that experts consider meteorological and hydrological observation datasets (such as rainfall and stream flow) as the most important for basin-wide understanding of water management, followed by evaporation and temperature datasets. Climate projections datasets are also recognized as important for climate and ecosystem change adaptation. Land-use/land-cover, elevation/geology, river network/watershed are required as basic datasets for understanding local

Required datasets	Num. ans.
Rainfall (observed)	14
Stream flow (observed)	12
Land-use / land-cover	11
Climate projections	10
Elevation / geology	9
River network / watershed	9
Agriculture (type, production)	8
Population / demographic	8
Evaporation (observed)	7
Water infrastructure (dam, reservoir, irrigation canal)	6
Temperature (observed)	6
Soil	2

Table 10.2: Required dataseta as basin-wide common datasets

characteristics, as well as water infrastructure such as reservoirs, dams and irrigation canals.

In addition, we asked what spatial datasets could be provided by the experts if a Mekong data sharing center was established by an approved international organization. Table 10.3 hows that observed datasets such as rainfall, stream flow and temperature as well as land-use/land-cover datasets could be potentially provided by experts. This result shows a clear gap between datasets required by experts (shown in table 10.1 and 10.2), and the potentially available datasets that can be shared by experts (table 10.3) if a data sharing mechanism, namely through a spatial data sharing center, was established.

Needless to say, the importance of data sharing and establishment of such system are recognized and many trials have been implemented in many places. In the questionnaire, however, our focus was to understand which incentives would motivate researchers and other experts to share their spatial data into a data sharing system, if for example, a spatial data sharing center for the Mekong was to be established. Table 10.4 shows their responses. Top of the incentives list was the potential for acknowledgement by a reliable intentional organization such as the United Nations (UN), IPCC, and Mekong River Commission (MRC). This gained more votes than other incentives such as receiving satisfaction from making a scientific and social contribution, or being referenced in scientific journals. This result provides valuable insights

Category	Spatial extent	Attribute	Data format	Resolution	Num. of answers
Observed data	Lower Mekong basin	Bisource, Temperature, rainfall wind, snow, fog	Point		6
Land-use/land-cover	Entire basin	Land-use/land-cover type	Grid Polygon	1:100,000 30m	4
Agriculture Aquaqulture	Cambodia	Rainfed crop and rice	Polygon		2
Geography / Geomorphology	Lower Mekong	Main stream & tributaries, land form			2
Other					1
I don't have own data					1

Table 10.3: Potential datasets that the experts could share

into the incentives that would be required for motivating experts to contribute their own datasets into a data-sharing center.

Available spatial datasets on the Web

Current available spatial datasets on the Mekong, at the basin-wide, regional and local scales, are investigated through web searches and interviews with local authorities. Through multi-scale surveys of available datasets, we considered the type of data and parameters needed, and what spatial and temporal resolutions are urgently required in order to establish common datasets. The aim is to help researchers consider what can be done for datasets to be improved. We hope this will facilitate spatial data sharing among collaborative researchers. Unless datasets are improved, it is difficult to drastically change the present situation in terms of a basin-wide scientific inquiry.

For example, table 10.6 shows that basin-wide land surface data such as land-cover and land-use, soil, and populations are available to use, but the spatial resolutions are too rough for accurate scientific analysis. The table also organizes the available datasets which cover the entire Basin, or which cover the country level, as well as those which has several observation data stored by an individual country but not always shared among countries.

Incentives	Num. of answers
Acknowledgement by a reliable international organizations or authority such as UN, IPCC, and MRC	9
Satisfaction of scientific and social contribution	5
Referenced at scientific journals,	4
I have no / very few data	8
Other	1
Money	0

Table 10.4: Incentives for sharing his/her spatial data

The search for available spatial datasets is still an ongoing process, but in addition to this, a literature survey was conducted to identify common datasets used for climate and ecosystem change assessment and adaptation. The literature survey included a review of global environmental assessment reports such as the IPCC Fourth Assessment Report: Climate Change 2007, Millennium Ecosystem Assessment (2005), and UN World Water Development Report (2009). As a tentative summary of the current situation of spatial data sharing in the Mekong, we found: 1) differing spatial and temporal resolutions; 2) varying levels of reliability; 3) out-dated or infrequently updated data. Also, countries and organizations have taken insufficient action for improving data sharing. To address these issues, new actions for creating basin-wide datasets are required urgently, namely Integrated, Open, and Dynamic action.

DESIGNING A SPATIAL DATA SHARING SYSTEM FOR THE MEKONG

A paradigm shift is occurring in the sharing of data worldwide towards more open accessible platforms and greater visualization of data on public websites, like Swivel and Google Earth (Butler, 2007). These websites provide immediate and powerful visualization of vast amounts of complex data in a form digestible by the general public. For researchers, it also encourages more efficient and effective methods of improving one's knowledge and technical skills through open access web systems. This new trend generates not only the development of science and technology, but also leads to increased communication and understanding between groups of people from different disciplines,

Category	Name	Year		Extent	Datasource		Data type	Rolution /scale
		Published	Last Update		Distributor (publisher)	Creator		
Population	Population Density 2000	2003	2000	LMB	MRC: People and the Environment Atlas of the LMB	MRC	Grid	1,000m
	Population by State-Province	2006	2004	EMB	ESRI	ESRI	Polygon	State-Province
	Urban Centres	2003	2002	LMB	MRC: People and the Environment Atlas of the LMB	World Population Gazetteer 2002	Point	
Land Cover	Land Areas	2006	2004	EMB	ESRI	ESRI	Polygon	Globe
	Lower Mekong Basin forest and land cover types 1993, overlaid with 1997 data	2001	1999	LMB	MRC	GTZ, MRCS	Coverage	1/250,000
	Land Cover 1997	2003	1999	LMB	MRC: People and the Environment Atlas of the LMB	MRC	Grid	250m
	Landsat Mosaic 1990	2003	1990	LMB	MRC: People and the Environment Atlas of the LMB	NIRE	Grid	30m
	Landsat Mosaic 2000	2003	2003	LMB	MRC: People and the Environment Atlas of the LMB	BDP, MRC Secretariat	Grid	30m
Soil	Soil Map of the Lower Mekong Basin	2002	2003	LMB	MRC	ASU, SSLCC, IRMC, Sub-NIAPP	Coverage	1:50,000 - 1:100,000

Table 10.5: Avaiable GIS datasets in the lower Mekong river basin

Category	Name	Year		Extent	Datasource		Data type	Rolution /scale
		Publish	Last Update		Distributor (publisher)	Creator		
Population	Population Density 2000	2003	2000	LMB	MRC: People and the Environment Atlas of the LMB	MRC	Grid	1,000m
	Population by State-Province	2006	2004	**EMB**	ESRI	ESRI	Polygon	State-Province
	Urban Centres	2003	2002	LMB	MRC: People and the Environment Atlas of the LMB	World Population Gazetteer 2002	Point	
Land Cover	Land Areas	2006	2004	**EMB**	ESRI	ESRI	Polygon	Globe
	Lower Mekong Basin	2001	1999	LMB	MRC	GTZ, MRCS	COVERAG	1/250,000
	Land Cover 1997	2003	1999	LMB	MRC: People and the	MRC	Grid	250m
	Landsat Mosaic 1990	2003	1990	LMB	MRC: People and the Environment Atlas of the LMB	NIRE	Grid	30m
	Landsat Mosaic 2000	2003	2003	LMB	MRC: People and the Environment Atlas of the LMB	BDP, MRC Secretariat	Grid	30m
Soil	Soil Map of the Lower Mekong Basin	2002	2003	LMB	MRC	ASU, SSLCC, IRMC, Sub-NIAPP	Coverage	1:50,000 - 1:100,000

Table 10.6: Avaiable GIS datasets in the lower Mekong river basin

industries and communities. In this regard, we need to further progress the "next generation" of data sharing, particularly in the area of environmental and disaster management. Firstly, requirements for future data sharing are identified by considering new trends on concepts and technologies for web-based data sharing. Secondly, two case studies are introduced which demonstrate the use new technologies in data sharing for environmental management.

Analyzing the trend of new technologies: Next Generation of data sharing

By considering new trends in Web-based data sharing concepts and technologies, our aim is to clarify the major factors we consider as essential for future data sharing:

1. Accessibility: Web 2.0 platform

   The internet has brought remarkable benefits to society. This innovative development in communication has led to the significant and efficient flow of vast amounts of information. One of the ground-breaking mechanisms that have come out of the internet are the free-editing platforms which allow millions of users to see, add, upload, share and edit content. Free editing platforms, such as "wiki platforms" have allowed networks to expand at breakneck speed. Ward (2008) defines a wiki as "a piece of server software that allows users to freely create and edit" and a tool that "encourages democratic use of the Web and promotes content composition". Web 2.0, a new web concept that is defined by Musser (2006) as "a more mature, distinctive medium characterized by user participation, openness, and network effects", has significant potential to develop information sharing systems in the disaster and environmental management fields (Mills, et al, 2009).

2. Accountability: Providing raw data

   There are numerous kinds of data sharing mechanisms that can be used to disseminate data to the public in various fields. However, the outputs are usually already processed numbers or information. If this processed data came from a different country or unfamiliar fields, it is considerably difficult in terms of understanding the reasons of and methodology used in the data processing, let alone using such data for alternative purposes. Providing actual raw numbers and information makes a significant change in terms of understanding and efficiency for both users and providers. Butler (2007) illustrates that if research organizations and journals linked the raw data behind papers to social software tools such as Swivel and Many Eyes,it would have considerably value to the scientific community as a whole.

3. Functionality: Analytical function and visualization

   Touching and editing data is the third critical characteristic of this new generation data sharing. In other words, data functionality – how users interact with the data to make it useful to them and others is as important as simply adding the information or data to the internet. For example, Swivel is one of the most well-known public data sharing services. Their concept is to "see the data, understand it, and share it (Swivel, 2010)". All of the provided raw data is set through an excel file, which can then be selected for the application of various analytical functions. Google Earth is another great example of a data visualization tool. The service provides geographical data sets, satellite images and various other functions. These on-demand analytical functions efficiently and effectively make people understand the numbers and products quickly through actual visual and hands-on experiences.

4. Communicability: Mobile and Twitter

   These applications are not only used to communicate with other people, but also have the potential to respond to disasters. The number of internet users worldwide has dramatically increased by almost 380% in a decade. The number of internet users in Asia is the highest among the world, even though only 14% of Asia's population has internet access to date. Interaction between people across the world is increasing through the internet. Communication applications such as Twitter, which allows users to send messages of less than 140 characters to others, are increasingly popular globally, especially in developed countries. Sharing information instantly with others makes for stronger, more mobile networks. These communication applications have also been applied to emergency situations and can significantly change the form of response to disasters. (Mills, A., 2009) InSTEDD is one non-profitable organization successfully using SMS to share geographical information under emergency situations. The Mekong Collaboration Program (MCP) strengthens networks between local communities and national governments, and international and regional organizations to confront epic outbreaks of disease. The organization collects data and information through GeoChat, which alerts public with spatial information and also provides a picture of the surrounding situation through mobile phones, which can aide responses to emergencies (InSTEDD, 2010).

5. Flexibility: Cloud computing and Mashup

   A movement is occurring in information technology and it is the "shift in the geography of computation" (Hayes, 2008). Installing software onto a personal computer is now becoming an old form of computing. "Service over the Internet and the hardware and software as a service (Armbrust, M., et al, 2009)" should be the new concept of computing today. In addition to this, "Mashup", defined as a "technique for building applications that combine data from multiple sources to create an integrated experience (Clarkin and Holmes, 2007)", can efficiently demonstrate various functions without installing software. This liberalization in computing encourages significantly enhanced information sharing and great advancements in science and technology.

Two case studies that use new technologies of data sharing for environmental management in different scales

Two case studies are introduced to demonstrate how spatial data sharing has been advanced for environmental management: Project Haiti and the International Data Sharing Mechanism IPCC-Data Distribution Centre.

Project Haiti: Wiki and Open Street Map

The Haiti earthquake resulted in more than 200,000 deaths and affected almost 3 million people since it hit the island on 12 January 2010. This amounts to almost one third of the population of the country being affected (UNDP, 2010). The earthquake inflicted devastating damage on people's lives, on all sectors of the economy, infrastructure and food supplies. In the aftermath, many countries and organizations immediately responded by providing various assistance measures. One area in particular was in data sharing and cooperation among those organizations, due to the lack of adequate information existing in the country. Under usual circumstances, the information provided can be confusing and disparate, making foreign assistance difficult; whether it's because of unfamiliarity with the geographic conditions or barriers to accessing correct information about roads, the location of people, etc.

OpenStreetMap (OSM) is a mapping service that provides "free geographic data" based on a wiki platform (OSM, 2010). Data is accumulated by individuals with GPS (Global Positioning System) devices and free satellite imageries. "WikiProject Haiti" was launched soon after the earthquake occurred. OSM efficiently provided geographical information/data to organizations, including UN agencies, nongovernmental organizations (NGO) and peacekeeping operations (PKOs). Data was transmitted immediately and ensured that operations on the ground could flow much more smoothly. Data collection of the WikiProject Haiti comprises roads and boundaries, transportation resources, water and sanitation infrastructure, health / medical facilities, and refugee camps (OSM, 2010).

International Data Sharing Mechanism IPCC-Data Distribution Centre (DDC)

DDC was established in 1997 with an objective to "facilitate the timely distribution of a consistent set of up-to-date scenarios of changes in climate and related environmental and socio-economic factors for use in climate impacts assessments" (DDC, 2010). DDC is mainly organized by the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA). The British Atmospheric Data Centre (BADC), the World Data Center for Climate (WDCC) and the Center for International Earth Science Information Network (CIESIN) at Columbia University are the co-organizers of the data sharing mechanism. All data and modeling methodologies are provided by reliable member organizations: the Deutsches Klimarechenzentrum (DKRZ), the Center for International Earth Science Information Network (CIESIN) and British

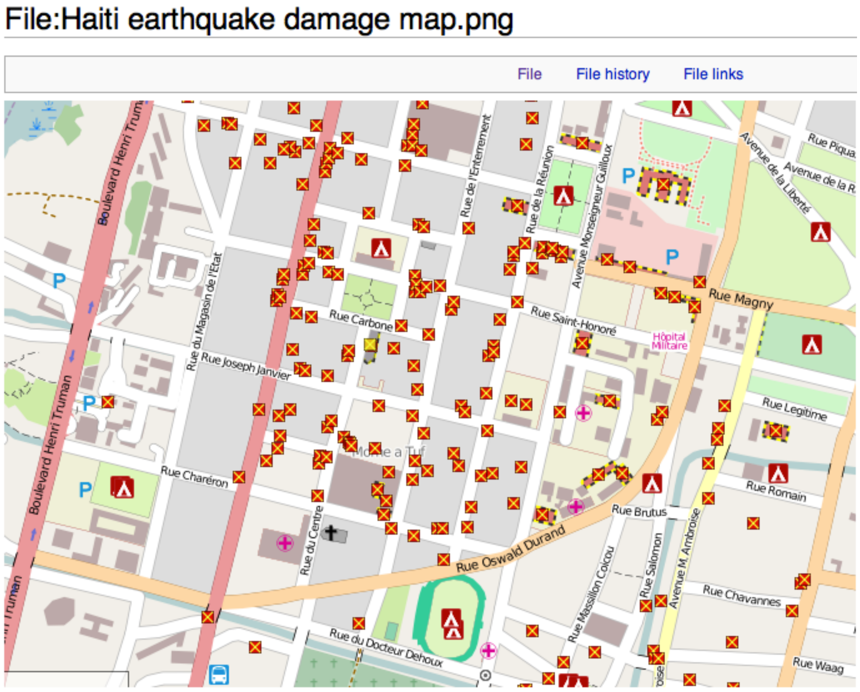

Figure 10.2: Haiti Open Street Map project(OSM 2010)

Atmospheric Data Centre (BADC) are the current main three centers. DDC provides desirable data sets related to climate change and these, such as climate observation data, socio-economical data, and environmental data, are used in IPCC assessment reports. Disseminating data collected by reliable institutes and making them open for public access can efficiently and effectively benefit local and global citizens who would normally have difficulty accessing this data. The DDC also offers a data visualization function in their service. All past data from the IPCC is free to download and a user can make a map with these datasets on demand. Provided data comes with meta-data, and the data format is also selectable e.g. in an Excel, NetCDF (network Common Data Form) or html format. This flexibility and accountability makes it possible for anyone, including decision makers, to efficiently apply data (DDC, 2010).

Comparison between Project Haiti and DDC

Risk management of environmental problems is diverse across various scales. As table 10.7 indicates, rapid environmental change such as floods and tsunamis need immediate cooperative action to mitigate potential disasters. On the other hand, slow changes like drought ne-

		Focusing on Specific topic	Specific Area	Synthetic
Spatial Scale	Area	Local	Regional	Global
	Management structure	Small scale community base	Middle sized research group	Large scale
Temporal Scale	Duration	Municipalities	Medium	International research groups
	Urgency	Short	Medium	Long
Charact- eristic	Target	High	↔	Low
	Clarity of the problem	Each event and biological phenomena	↔	Multi- dimensional and social phenomena
	Characteristic of the risk	Impact can be seenResilience is the focus	↔	Uncertain Difficult to observe, and predict the event.

Table 10.7: Targeting Scales and its characteristics for risk management

cessitate more long-term and large-scale integrated risk management approaches. Under emergency circumstances, getting the right information or data is the first priority, in comparison to modeling climate change which requires more accuracy and quantity. Established data sharing arrangements differ according to each identified scale. There are definite differences in data sharing between the Haiti earthquake and water resource management in the Mekong River Basin, primarily in both spatial and time scales. The emergency situation in Haiti needed immediate cooperation by organizations and countries in the sharing of information in order to respond with relief efforts urgently.

In relation to water management in the Mekong, longer-term combined efforts are required. Confrontation over water management and flood control are key issues that concern people of the Mekong. To achieve sustainable water resource management, accurate data suitable for modeling is important. In this regard, improved observation data should be collected by researchers, institutes and universities.

Demonstrating an image of spatial data sharing system

Data sharing in transboundary basins tend to have numerous problems. For example, the Himalayan transboundary area, a mountain environment severely affected by climate change, is also afflicted with political tension (Sharma, E., et al. 2009). To address this issue, data sharing on a regional scale was required and the International Centre for Integrated Mountain Development (ICIMOD) took the initiative to introduce a scientific network to tackle climate impacts on the region. Observation data, such as temperature, wind speed and river discharge is needed to implement models for water management across the region, the outcomes of which are relevant to decision making and necessary for coping with climate change impacts. In the case of Himalayan cooperation however, only data greater than 5 years old could be shared; which is inadequate for managing rapid changes in climate and ecosystems. Data formatting requirements also differ. Consolidation or modification of data collected from member institutes is a big challenge in ensuring the data sharing system is accountable for science and society. Another challenge is whether the data should be made open to the public or not, although this matter can be resolved by having parallel sites, similar to Swivel which provide total open access, but also has private access incorporated mainly for business use (Cyranoski, 2008., Swivel, 2010).

Our goal is to promote integrated water management in the Mekong Basin through advanced utilization and sharing of spatial data provided by each country, institute or organization, as well as further ensure the region's water security through improved accuracy and quantity of data collection. Interaction among scientists, practitioners, and even policymakers would be one of the primary components in reaching our goal. The Mekong spatial data sharing center should be established based on a web 2.0 concept and technology: for example, wiki type, open access platforms can be suitable for developing the Mekong regional network. Each university and representative of a country in the transboundary area can share raw data with meta-data, making overall data more reliable and useful. The spatial data centre can also provide methodologies for water modeling and ecosystem management in the Mekong region. Visualization and analytical functions need to be incorporated in the data-sharing platform, ideally based on cloud computing. This function will provide a platform for interaction between the academic community and public in the Mekong basin, including the localization of information.

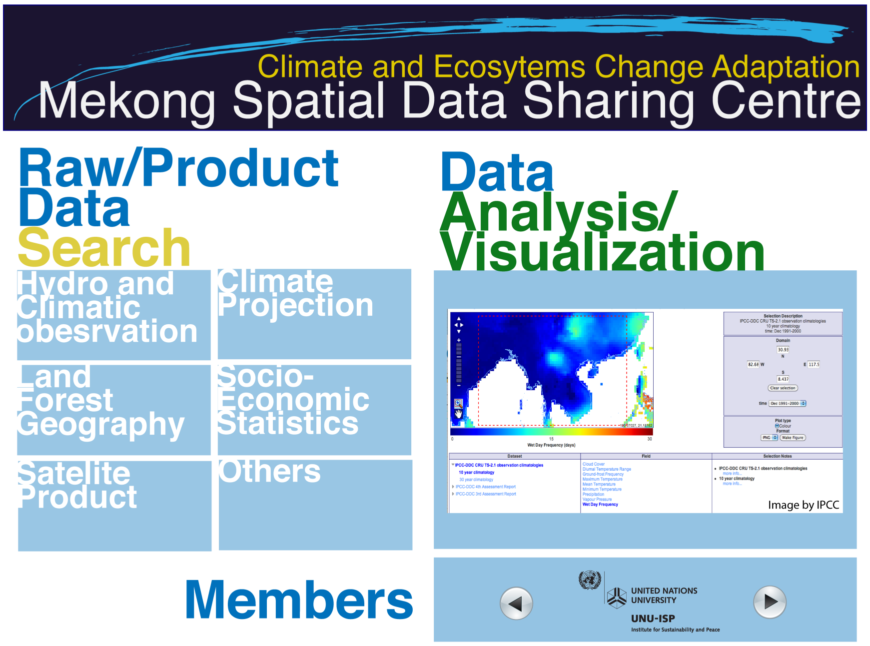

Figure 10.3: An image of top pages of the Mekong spatial-data sharing center

We propose to establish a spatial data-sharing center in the entire Mekong basin for climate and ecosystems change. Figure 10.3 and 10.4 are proto-typed images of a future web-based data-sharing platform. The web system should meet expert's needs as highlighted in section 2.1. One complication of data searching systems or websites in general is the ability of people to utilize web data sharing services. Therefore, the design of the search function should be simple. For example, a search function could simply be divided into 6 categories, relating to the results of table 10.2, such as "Hydro and climatic observation". These would constitute the most required datasets for conducting research. Data format conversion is another barrier highlighted in section 2.1. Thus, providing a variety of data format sets is a necessary function in order to satisfy peoples' and organizational needs.

REMARKS

This study demonstrated the value of utilizing basin-wide common datasets and its sharing system, using the Mekong River Basin as a case study. It also discussed how to improve data sharing to enhance countries' responsiveness and adaptation to climate and ecosystems change, and address transboundary issues.

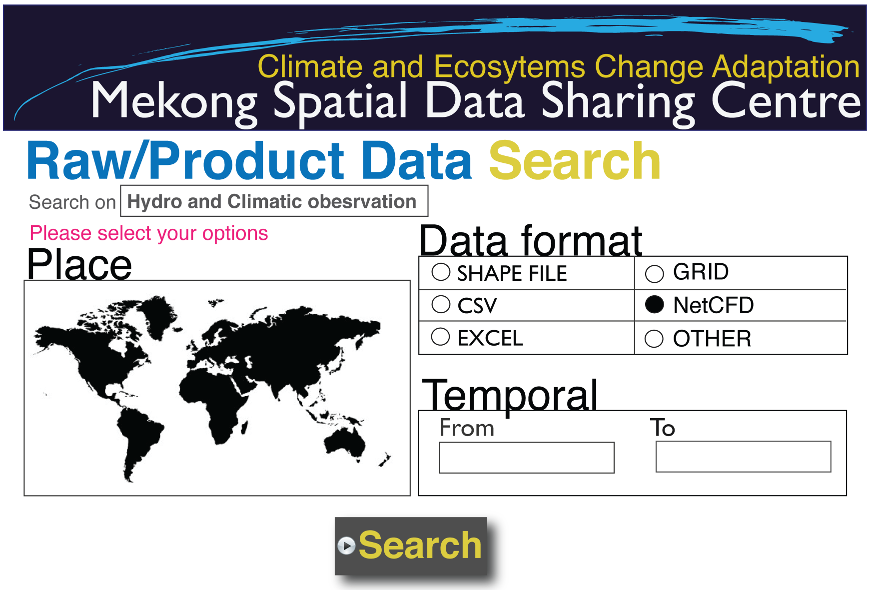

Figure 10.4: An image of spatial-data search page

The following surveys were conducted to assess the current situation of available spatial datasets and future demands: 1) expert needs questionnaire; 2) survey of available spatial datasets on the web; 3) survey of common datasets in global environmental assessments. Following this, a prototype for a spatial data sharing system was proposed based on analysis of upcoming trends in new technologies and clarification of system requirements by experts.

As results of the conducted surveys: a) the need for basin-wide common datasets was demonstrated; b) using new and innovative ideas and technologies in data sharing, more communication and better sharing of information in transboundary basins can be realized; c) As a UN agency, United Nations University has an important role to play in the Mekong transboundary basin to encourage the regional scientific community to co-operate through spatial data sharing to cope with climate change; d) this can thereby, support local communities to adapt to climate change impacts; and finally; e) establishing a regional data sharing center might provide significant assistance to scientists, policy makers and the broader society in its efforts to confront climate and ecosystems changes.

We hope that our results can contribute to promoting basin-wide scientific investigation and collaboration. As an ultimate goal, we hope that the creation of common datasets and establishing a data sharing system can be an effective tool for climate and ecosystems change adaptation in the Mekong River Basin.

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11

PROACC - AN INTEGRATED POST-DOCTORAL RESEARCH PROGRAMME ON ADAPTATION TO CLIMATE CHANGE IN THE MEKONG RIVER BASIN

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ABSTRACT

The recently initiated Post-doctoral Programme on Climate Change Adaptation is introduced. In the first phase (2010-2011) the focus of the project is the Mekong River Basin. The programme is described including the organization, deliverables and collaborating partners. All post-doctoral fellows come from the region and will be hosted by local/regional knowledge institutes. Beside the generation of new scientific knowledge, the projects will try to translate the findings into the development/implementation of effective climate change adaptation strategies in the respective Mekong countries. It can be expected that this programme will strengthen regional cooperation further and that the post-doctoral fellows will continue to work on related topics in the region after this phase of the programme will be finished end of 2011 (capacity building component of the project).

INTRODUCTION

Climate Change has already and will have great implications for water and the environment. In general, the impacts in the South are likely to be greater than in the North, as many developing countries and countries in transition are located in southern areas that are expected to be very sensitive and vulnerable to climate change ('hot spots') and because resilience in those countries is less developed. Climate change impacts are often also amplified by other pressures on the environment such as rapid population increase, land use change, urbanization, change in natural resources and their management etc. In many developing countries the challenge to meet the Millennium Development Goals (MDGs) increases due to these impacts.

It is still poorly understood how the impacts of climate change and other global changes interact, and which adaptation measures will be possible and suitable given local/regional settings. The uncertainties and knowledge-gaps are increased by the extreme spatio-temporal variability of climate change impacts. Uncertainty about future climatic conditions is also significant, particularly at local and regional scales. The capacity to cope with climate change impacts is very limited in developing countries and many countries in transition. This has increasing and dramatic implications on water and the environment as well as on human beings. All these points seem to be true for the Mekong River Basin in south-east Asia (Eastham et al. 2008).

To address these challenges, UNESCO-IHE in collaboration with partner institutions has set an up Post-doctoral Programme on Climate Change Adaptation (PRoACC). In the first phase (2010-2011) the focus of the project lies in the Mekong River Basin. It is expected that the eight individual post-doctoral research fellows will carry out their research in close collaboration with key stakeholder groups from the Mekong River Basin. It is highly desirable that the research outputs will facilitate the development/implementation of effective adaptation strategies in the respective countries. Thus, besides carrying out the research, it will be attempted to translate the scientific findings into the development/implementation of better policies in the field of climate change adaptation. In addition, the capacity building aspect of this post-doctoral programme is significant. All post-doctoral fellows come from the region and will be hosted by local/regional knowledge institutes. This will strengthen regional cooperation further and the objective is that the post-doctoral fellows will continue to work on related topics in the region after the programme is finished.

STUDY AREA: THE MEKONG RIVER BASIN

The Mekong River Basin is a large international river basin (almost 800,000 km2) and is shared by six countries: PR China (Lancang sub-basin), Union of Myanmar, Lao PDR, Kingdom of Thailand, Kingdom of Cambodia and Viet Nam. More than 70 million inhabitants live in this basin, mainly in rural areas and, consequently, the livelihoods depend to a significant extent on agriculture. The rapidly growing population (about 2% per year) causes often conflicting demands on the water and land resources, in particular in the lower Mekong River Basin. Fortunately, the riparian countries recognized the need for a collaborative and integrative water resources management long ago. The Mekong River Commission (MRC) (focus on the lower part of the river basin; established in 1995) can look back on a history of coordinative water resources development of over 50 years in this region. Recent attempts and developments have been bringing the upper part of the basin closer to the other countries and a regional cooperative development approach.

The water resources availability varies widely in space and time in this river basin due to the monsoon rainfall pattern and the variability in the physiographic characteristics (topography, geology, soils, land use etc.). The total discharge varies significantly with an average of 25,000 m^3/s during the rainy season (July-November) and only 2,000 m^3/s during the dry season (December-March). The water resources as a whole are not fully developed and to some extent poorly understood (e.g. groundwater resources), but there are several issues related to the water resources such as (Chu Thai Hoanh et al. 2003, IPCC 2007, Eastham et al. 2008, Kummu et al. 2008):

- Further development of irrigation connected to further intensification of food production (change of cropping pattern, increased dry-season production, calendar, more harvests per year, increased fish production);
- Floods and flooding with an increase of the damage potential in the last years;
- Reduction of low flows due to (mainly agricultural) water use upstream and consequently increased sea water intrusion in the delta region;
- Hydropower development (proposed or under development) with unequal benefits across the riparian countries and sectors involved;
- Land use changes (e.g. deforestation and maybe local reforestation efforts as adaptation measure; local urbanization) with impacts on local and regional water cycle dynamics;
- Rapid population growth and economic development impacts water resources quality (surface water and groundwater); and

- Climate change has been evident over the past decades and it is possible to cause further shifts in the monsoon weather patterns with increasing floods (more intense rainfalls) and droughts (longer and more severe dry spells), possible increased number of tropical cyclones, more severe heat waves in particular in larger urban areas, and possible more extensive ENSO phenomena with impacts on the regional climate; on top of that sea levels will rise with significant impacts on coastal regions.

All these issues make the development of well-informed, scientifically sound adaptation measures in the whole river basin essential. Water is key in that respect. The vulnerability to climate change makes this river basin a suitable study area for the post-doctoral programme. Increasing the knowledge base about the interplay of climate change and other changes (with various poorly understood positive and negative feedbacks) in this river basin through well-targeted, interdisciplinary scientific research is essential for future sustainable planning and development of water resources. This needs an integrative water research approach as the adaptation measures cut across all sub-disciplines of watershed sciences including natural sciences, engineering and social sciences. Existing research activities in the region are the starting point for the programme.

organization of the proacc programme

Recognizing that the most productive period in a scientific career is often the first five years following the completion of the PhD, this programme will focus on post-doctoral research. In addition, UNESCO-IHE in collaboration with its partners will augment its capacity development offers with this programme and contribute to enhancing the research capacity in the countries of the study area. The post-doctoral researchers will undertake their research under the guidance of a supervision team that includes a professor or senior researcher of UNESCO-IHE and a professor or senior researcher of a partner institute in the Mekong region and representatives from stakeholders. The duration of the research project will initially be 18 months.

During the programme the following meetings will be held to stimulate cooperation, synergies and interdisciplinary research:

- Inception workshop (start date: 26 April 2010)
  - Date : 1st week of the project

- Duration: approx. 1 week, incl. specialized training after that week while the fellows are still in Delft
- Location – UNESCO-IHE, Delft, Netherlands,
- Participation – all post-doctoral researchers and UNESCO-IHE supervisors, if possible partner representatives and members of the Scientific and Policy Advisory Committee (SAC) (see below)

- Integration workshop
  - Date : approx. 9th month of project
  - Duration: 2-3 days
  - Location – at a partner institute in Mekong region (e.g. MRC, AIT,Water Resources University Vietnam (WRU), Chinese Partner)
  - Participation – all post-doctoral researchers and respective supervisors, mentors/collaborators, members of the SAC as far as possible
- Synthesis workshop ('Final ProACC Symposium')
  - Date : 18^{th} month of project
  - Duration: 2 days mainly internal workshop and last day 'symposium day' for the general public (>200 participants)
  - Location – UNESCO-IHE, Delft, Netherlands, or at a partner institute (e.g. MRC, AIT, WRU) or connected to a regional scientific and/or knowledge exchange event (e.g. Annual Mekong Flood Forum, Yangtze River Forum)
  - Participation – all post-doctoral researchers and supervisors from UNESCO-IHE and partner institution, other collaborators, representatives from stakeholders, members of the Scientific and Policy Advisory Committee and other interested parties
  - Proceedings: Short papers should be presented for each post-doctoral project; in addition, further synthesis papers should also be presented. The papers will be compiled into special proceedings.

It is anticipated that the dissemination of project outputs will take place in various ways, such as:

- Several peer-reviewed journal articles per project (minimum two per project) as well as joint articles originating from cluster projects
- Proceedings of PRoACC Symposium (as above)
- Special sessions at a major international conference (e.g. Stockholm Water Week 2011, EGU, AGU, Annual Mekong Flood Forum etc.)
- Special issue of an international journal (e.g. Climatic Change) Policy briefs outlining the potential implementation of the project outputs in 'on-the-ground adaptation strategies' (minimum one per project); and
- Digital case studies (e.g. animated PowerPoints with movies etc.) to be used as educational product. These case studies will be made available to the public via the UNESCO-IHE and partner institute websites.

The programme is managed by a Steering Committee (SC) at UNESCO-IHE (led by Prof. S. Uhlenbrook, Programme Director, and Dr. W. Douven, Programme Manager). In addition, a Scientific and Policy Advisory Committee (SAC) was set up. It is composed of external experts and includes representatives from partner institutions. Its main task is to give advice on scientific contents and policy linkages of the post-doctoral research projects and the overall programme.

participating groups

A number of core groups of UNESCO-IHE participate in the programme ranging from Water science and engineering (hydrology, hydraulics, sanitary engineering, hydroinformatics) to environmental sciences (fresh water ecology, pollution prevention and control) and social sciences (water management, water governance and water economics). Staff members from these groups will, jointly with partners, supervise the post-doctoral fellows. In addition, a number of partner institutes in the region were invited to participate (table 11.1); note that this list is not exclusive. Some of these institutes will be hosting of post-doctoral fellows and staff members will jointly supervise the fellows.

Asian Institute of Technology, ATI, Bangkok, Thailand
Water Resources University, WRU, Ha Noi, Viet Nam Vietnam Institute of Meteorology, Hydrology, and Environment, Hanoi, Vietnam Vietnam National University, Hanoi / HCMC, Vietnam
Cantho University, Cantho, Vietnam Mekong River Commission, MRC, Vientiane, Lao
Changjiang Water Resources Commission, CWRC, Wuhan, China Changjiang River Scientific Research Institute, CRSRI, Wuhan, China Changmai University, Unit for Social and Environmental Research (USER), Changmai, Thailand
Hohai University, Nanjing, China
Nanjing Hydraulic Research Institute, Nanjing, China
Tsinghua University, Center of International Transboundary Waters and Ecosecurity, Beijing, China
Chinese Academy of Sciences, CAS, Beijing, China Yunnan University, Asian International River Center (AIRC), China
Southern Institute of Water Resources Planning (SIWRP), Vietnam
Southern Institute of Water Resources Research (SIWRR), Vietnam
Royal University of Phnom Penh, Cambodia
National University of Lao, Lao PDR
Khon Kaen University, Mekong Institute, Thailand
To be determined

Table 11.1: Partner Institutions from Mekong River Basin Countries

concluding remarks

A Post-doctoral Programme on Climate Change Adaptation was set up by UNESCO-IHE in collaboration with partner institutions, which will in the first phase (2010-2011) focus on the Mekong River Basin as study area. Eight post-doctoral research projects will start April 2010 for a period of 18 months. All come from the Mekong region and are hosted by institutes in the region. They will carry out their research in close collaboration with key stakeholders. It is highly desirable that the research outputs will facilitate the development/implementation of effective adaptation strategies in the respective countries. Thus, besides carrying out the research, it will be attempted to translate the scientific findings for the development/implementation of better policies in the field of climate change adaptation.

acknowledgment: This project was funded by the Dutch Development Cooperation, DGIS, The Hague, The Netherlands.

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Part II

WATER SECURITY

12

RESPONSES OF FLOW VARIATIONS TO PRECIPITATION CHANGE ALONG THE UPPER MEKONG MAINSTREAM IN THE DRY SEASON

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ABSTRACT

In this paper, a quantitative examination based on the monthly flow records from 1960 to 2003 at four main stream sites in the Upper Mekong River (UMR), was undertaken to identify the characteristics of the mean flow variation in the dry season and its response to precipitation change. The major results are: (1) there is no significant correlation between the flow variation in the extreme dry season (DF) and precipitation variation in the up-midstream of the UMR, which means that the precipitation variation has little influence on the DF variations, and the latter are mainly controlled by the supplement variation of groundwater and snow melting. (2) In the downstream, the DF variations are influenced by both the DF variation in the midstream and the precipitation variation in corresponding key regions of precipitation (KRP). Especially after 1995, the precipitation in the KRP has more significant influence on the DF variation in the downstream than that in the midstream, so the DF variations in the downstream show different trends with that in the midstream. (3) The periodic oscillation of DF in the upstream shows stable 5 year, 9 year and nearly 15~16 year oscillation cycles; The DF in the midstream shows stable 13 year cycle evolution, but its interannual oscillation cycles change around 1975 and 1985; Due to the influence of precipitation variation, the DF variation at Gajiu hydrological site shows different periodic oscillation from Jiuzhou site in the midstream after 1993; The periodic oscillation of the DF variation at Yunjinghong hydrological site shows similar feature with that in the midstream, changing around 1975 and 1985.

INTRODUCTION

Flowing through six countries, the Mekong River is the most important international river in Southwest China and Southeast Asia. Precipitation in the upper Mekong River Basin is strongly influenced by the southwest monsoon, which is unevenly distributed throughout the year.About 70% of annual precipitation is concentrated in the wet season during May-October, which results in unevenly distributed runoff. Runoff in the lower Mekong is much more plentiful than runoff in the Upper Mekong River (UMR)[1, 2] .

Due to the interconnected nature of hydrologic systems and the dynamic nature of water, transboundary rivers present a formidable challenge to the fixed and arbitrary political boundaries that make up today's world. This is especially true regarding how much of an influence of the upstream development may have on downstream countries, communities, and ecosystems. And the transboundary influences of dams in international rivers have the characteristic of complexity and political sensitivity, making comprehensive assessments even more difficult [3-8]. Especially for the cause of abnormal flow variation in the Mekong River Basin during drought period, it has been the focus of heated debate, with quite different opinions and results over the past ten years: Quang and Nguyen[10] and Siew[11] indicated that the low water-level fluctuations in the dry period in the lower Mekong River have been significantly influenced by the operation of the Manwan Dam. J and Yu[12] indicated that the negative impacts of dams construction may include increased downstream erosion, serious disturbance to fisheries ecology and the devastation of annual river bank gardening enterprises. Other authors, however, have raised concerns that environmental changes (e.g., climatic factors and land use) are the main cause of the hydrological variations in the Mekong River Basin[13-21]. Campbell[14-16] showed that the low flows in 2003–2004 were caused by low rainfall in the lower basin, rather than any activities upstream. Mekong River Commission (MRC)[21] and Li et al.[19, 22] indicate that the current dry conditions in lower Mekong are influenced by the local climatic factors. Cogels[11] stated that the Chinese dams are not responsible for the drought situation faced by downstream countries in recent years. He et al.[18] suggested that the upper Mekong cascade development would increase the dry-period flow volumes and decrease the wet-period flow in Lower Mekong, and Cogels indicates that this would be beneficial for drought management in downstream countries[11].

The main cause for the controversy above can be illustrated as follows:

1. The existing data and information are usually inconsistent and not unified among different riparian countries in the Mekong region;

2. An upstream-downstream dialogue mechanism at multiple levels does not exist[24].

3. There is still a lack of basin wide researches for the transboundary ecological and hydrological responses to the driving factors of global change (e.g. climatic changes, and human activities especially regarding dam construction and operation) and quantitative data investigating environmental change. Little attention has been paid to the multi-timescale correlation between the upstream and downstream flow variations.

Initially, research [19, 22], noticed that the flow variation during extreme drought periods in the downstream differed from that in the midstream. Without quantitative analysis towards identifying the cause of that, the difference has been simply considered as the result of hydropower development along the mainstream of Lancang Mekong river (i.e. UMR), which has been the focus of heated debate[10-12].

In this paper, based on the records of monthly flow from 1960 to 2003 at four mainstream hydrological sites in the UMR, a quantitative examination has been undertaken into characteristics of the mean flow in extreme drought period (DF) variation and the multi-timescale correlations of DF variations between the upstream and downstream. The responses to driving factors of precipitation change at the main stream are also investigated to reveal the cause of abnormal variation of the DF in the downstream. The results provide scientific recommendations for integrated water resources management (IWRM) in the Mekong River Basin.

DATA AND METHODS

Data

The flow data used in the paper are based on records of monthly change at the four main stream hydrological sites in the UMR (figure 12.1.a): (1) At the Changdu hydrological site in the upstream from 1960~1993; (2) At the Jiuzhou, Gajiu, Yunjinghong hydrological sites in the mid-downstream from 1960~2003. The four sites are located in stable reaches. Even at the Gajiu hydrological site, the nearest gauging station below Manwan Dam, is located in a rocky reach, the morphology of which

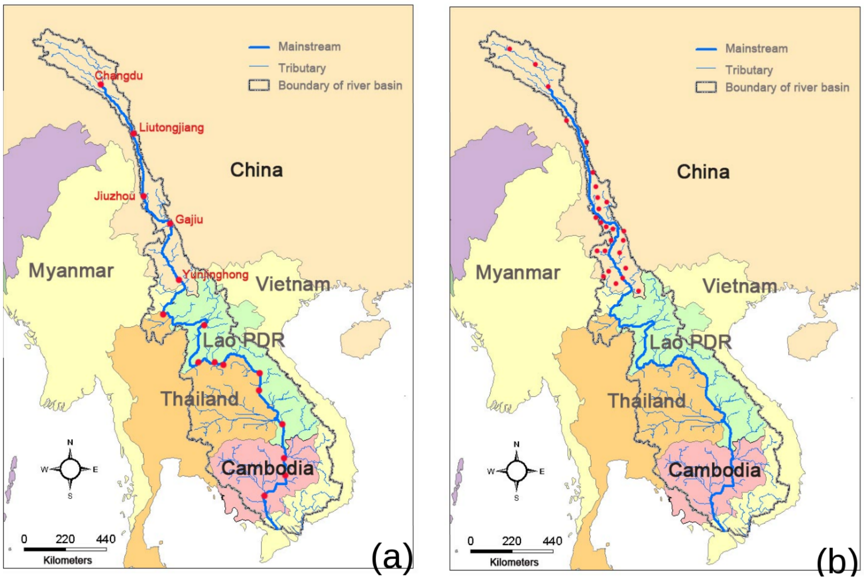

Figure 12.1: The locations of the mainstream hydrological sites (a) and meteorological sites (b) in the UMR basin

is unaffected by the outflow of the dam. Thus, the records at the four sites are consistent as the cross-sections of the measurements stations have been stable over the study period.

The meteorological data are based on records of daily precipitation from 1960~2004 at 24 meteorological sites which are selected according to geography and climate. Their location and general situation are shown in figure12.1.b. The locations of the selected sites distribute from the north to the south along the UMR and cut across the hinterland as well as the climatic region, which includes the plateau temperate zone, plateau subtropical zone, and the plateau tropical zone, and represent the climatic situations of most areas in the UMR basin.

Method

Using the binomial coefficient weighted average method and five-year moving average method[25], the DF variation can be divided into three factors: trend, interdecadal variation, and inter-annual variation. Trend is often influenced by large scale environmental variation (such as climate variation), and other factors including interdecadal and inter-annual variation are influenced by human activities (e.g. dam construction, irrigation or other water consume activities)[225]. Using the methods, the multi-timescale characteristic of the DF variations and their background environment variation can be shown. Based on Morlet wavelet analysis[25], correlation analysis and other statistical methods, the periodic oscillation of DF variations and corresponding precipitation variation can be revealed to explore the regional hydrological response to climatic changes in the UMR basin. The correlation of DF variation between upstream and downstream are also further investigated.

The characteristic of mainstream DF variations and their responds to precipitation variation

Based on the intra-annual allocation of monthly mainstream flow at Changdu, Jiuzhou, Gajiu, Yunjinghong hydrological sites, the extreme dry season of flow variation can be confirmed as follows: (1) From December to February of next year at Changdu and Jiuzhou hydrological sites in the up-midstream; (2) From February to March at Gajiu and Yunjinghong hydrological sites downstream.

Distribution of the key regions of precipitation in relation to the mainstream DF variation

According to the correlations between the variation of mainstream DF and precipitation in extreme dry season (DP) at surrounding meteorological sites, the distribution of the key regions of precipitation (KRP) is confirmed to reveal the precipitation influence on the mainstream DF variations. The results indicate that:

There is no significant correlation between the DF and DP variation at Changdu hydrological site (in the upstream) and Jiuzhou hydrological site (in the midstream), which means DP has little influence on the DF variations, and the latter is mainly controlled by the supplement variation of groundwater and snow melting.

As for the Gajiu hydrological site in the downstream, there is significant positive correlation between the DF variations and DP at these meteorological sites: Lanping, Yangbi, Yongping, Baoshan, Changning, Gajiu, Yunxian meteorological sties. Considering the contribution to streamflow at Gajiu hydrological site, the key region of precipitation for the DF at Gajiu hydrological site (KRP-GJ) is composed of Lanping, Yangbi, Yongping, Baoshan, Changning, Gajiu, Yunxian county (figure 12.2.a).

With regard to the Yunjinghong hydrological site in the downstream, there is significant positive correlation between the DF variations and DP at these meteorological sites: Lanping, Jiuzhou, Yunlong, Changning, Gajiu, Yunxian, Jingdong, Lincang, Zhenyuan, and Jinggu meteorologi-

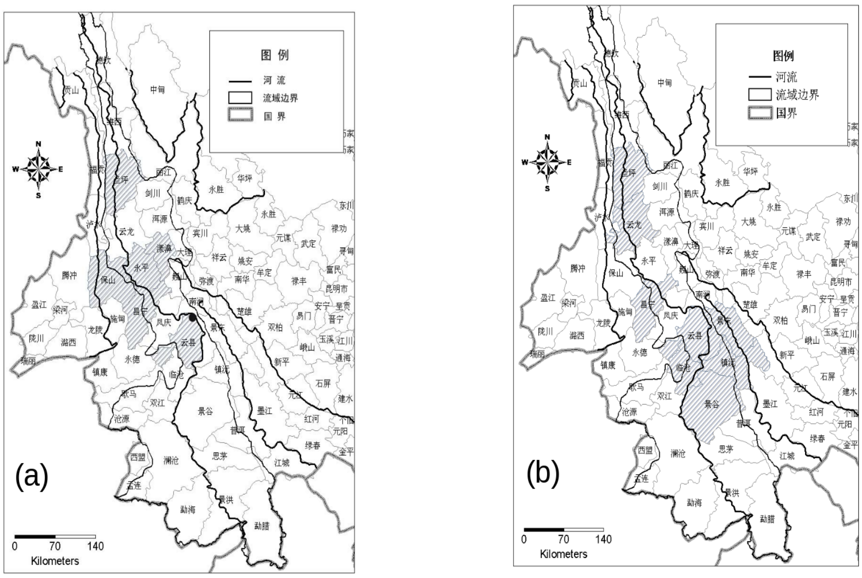

Figure 12.2: The distribution of KRP-GJ (a) and KRP-YJH (b) (shaded parts on a picture)

cal sties. Considering the contribution of these meteorological sties to streamflow at Yunjinghong hydrological site, the key region of precipitation for the DF variation at Yunjinghong hydrological site (KRP-YJH) is composed of Lanping, Jiuzhou, Yunlong, Changning, Gajiu, Yunxian, Jingdong, Lincang, Zhenyuan, and Jinggu county (figure 12.2.b).

As shown in figure 12.2, the distributions of KRP-GJ and KRP-YJH in the downstream are mainly located on the north to middle part of Yunnan Province, with larger area in the KRP-YJH.

To confirm the reasonability of the KRP-GJ and KRP-YJH, the correlation analysis is also applied on the mean DP (MDP) of the meteorological sites in KRP and the DF at two hydrological sites in the downstream. It can be found that the positive correlation coefficients between MDP and DF at two downstream hydrological sites all pass 99% confidence verification, which is 0.443 at Gajiu hydrological site and 0.414 at Yunjinghong hydrological site. This means that the variation of MDP in the KRP-GJ and KRP-YJH can be used to investigate the response of DF to precipitation variation in the downstream.

The characteristic of DF variations at multi-timescale in the up-midstream

As stated in the above, DF can be divided into trend, interdecadal, and inter-annual variation curves within the same coordinate plane based on both binomial coefficient weighted average method and five-year

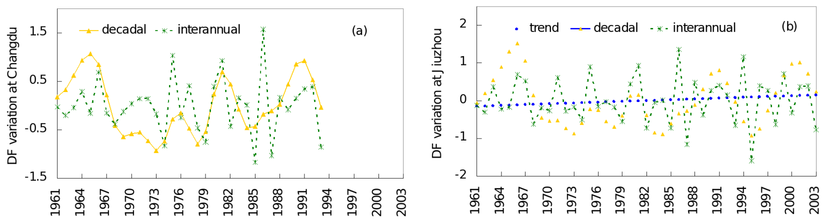

Figure 12.3: The trend, inter-annual and interdecadal variations of DF in the upstream and midstream (standardized value)

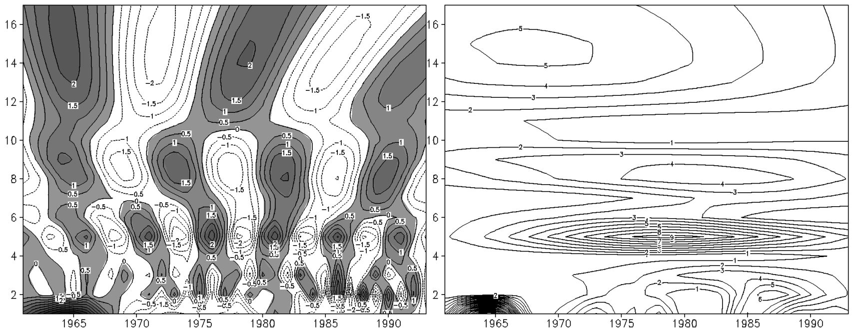

Figure 12.4: Wavelet transform coefficients of the DF at Changdu hydrological site (1960~1993)

moving average method. Figure 12.3 shows the departure curves of the trend, inter-annual and interdecadal variation of the DF at Changdu and Jiuzhou hydrological sites.

As seen from figure 12.3, the DF in the upstream and midstream (Changdu and Jiuzhou hydrological sites) all show a significant decrease from middle 1960s through early 1970s, and turn to increase from early 1970 to early 1990. In addition, the DF in the midstream (Jiuzhou hydrological sites) obviously increased after 1993 and began to decrease after 2000.

According to the Morlet wavelet analysis, the periodic oscillation pattern of DF in the mainstream of UMR can be revealed. It is noticed that the DF at Changdu hydrological site in the upstream mainly has periodic oscillation of 15 years, 9 years, 5 years, and 2 years (figure 12.4.a). As shown from squared module pattern (figure 12.4.b), stable 15 years, 9 years and 5 years oscillation cycles exist during 1960~1993 except that 2 years oscillation cycles steadily exist only after 1985.

With regard to the DF at the Jiuzhou hydrological site, it can be seen that oscillation cycles of nearly 12~13 years, 8 years, 5 years, and 2 years obviously exist in the midstream (figure 12.5.a). Figure 12.5.b shows that stable 12~13 years cycles exist during1960~2003, while other

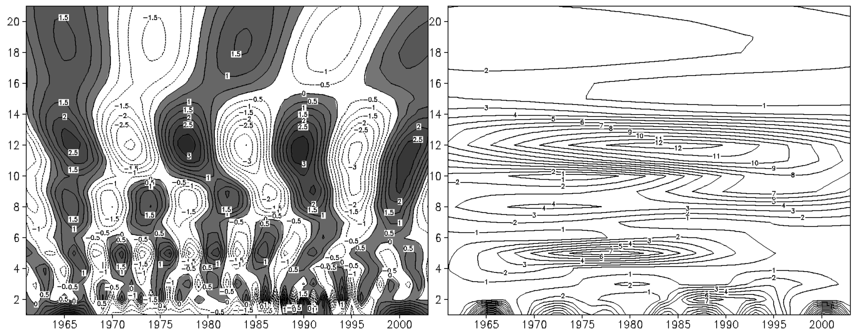

Figure 12.5: Wavelet transform coefficients of the DF at Jiuzhou hydrological site (1960~1993)

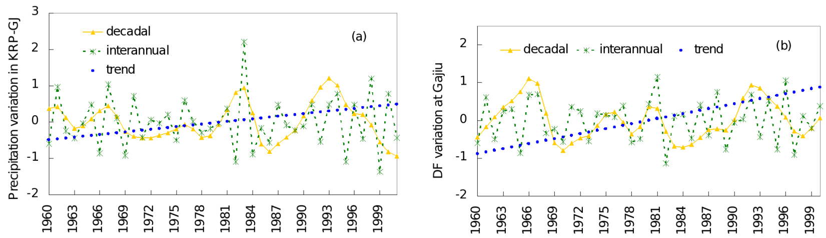

Figure 12.6: The trend, inter-annual and interdecadal variations of DF at Gajiu hydrological site (a) and MDP in KRP-GJ (b) (standardized value)

inter-annual oscillation cycles all change around 1985: 5 years and 8 years mainly steadily exist before 1985, while a stable 2 years oscillation cycles occurs from 1986~1995.

The multi-timescale characteristic and response of DF variations to climatic change in the downstream

In order to further investigate the response of DF to climatic change in the downstream, the multi-timescale characteristic and periodic oscillation pattern of the DF and MDP in KRP can be compared as figure 12.6~figure 12.8.

Gajiu hydrological site

As seen in figure 12.6.a, the MDP variation in the KRP-GJ shows significant increasing trend during 40 years. It increases obviously before 1992, and decreases obviously after 1993, in which it change into an especially dry year after continuing wet years from 1988 to 1991. Accompanying with the increasing trend of the MDP variation in the KRP-GJ, the DF variation at Gajiu hydrological site also displays predominant

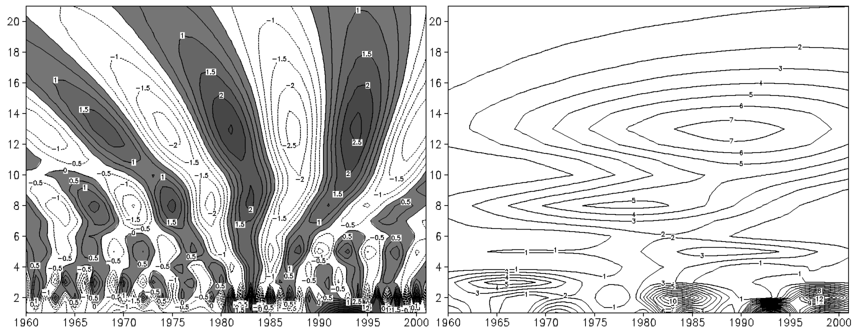

Figure 12.7: Wavelet transform coefficients of the MDP in KRP-GJ (1960~2001)

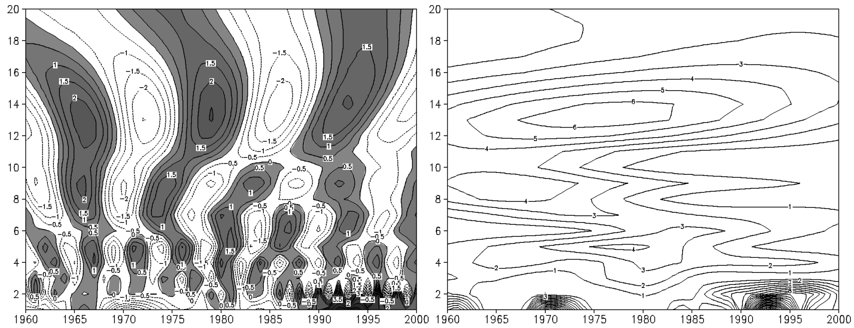

Figure 12.8: Wavelet transform coefficients of the DF at Gajiu hydrological site (1960~2000)

ascending trend, and shows similar trend with MDP in the period of 1970~1992 and 1993~2001.

According to the wavelet transform coefficients' real part (figure 12.7.a) and squared module pattern (figure 12.7.b) of the MDP in KRP-GJ, it can be found that the MDP variation in KRP-GJ exist 13 years, 8 years, 5 years, 3 years, and 2 years periodic oscillation cycles. In particular, stable 13 year cycles can be seen from 1960 to 2001, while other interannual oscillation cycles all change around 1980: Stable 3 year oscillation cycles can be seen before 1975, whereas stable 8 year oscillation cycles can be found before 1980. After 1980, stable 2 year and 5 year oscillation cycles occur.

Figure 12.8 gives the periodic oscillation pattern of DF at Gajiu hydrological site. It can be seen that the DF at Gajiu hydrological site exhibits similar features with MDP in KRP-GJ but different from the DF at Jiuzhou hydrological site in the midstream: Stable 13~14 year cycle evolution exists in the DF variation at Gajiu hydrological site during 1960~2001, while stable 5 year cycles exist from 1970 to 1990.

Therefore, the DF variation at Gajiu hydrological site is influenced by both the DF variation in the midstream and the precipitation variation in

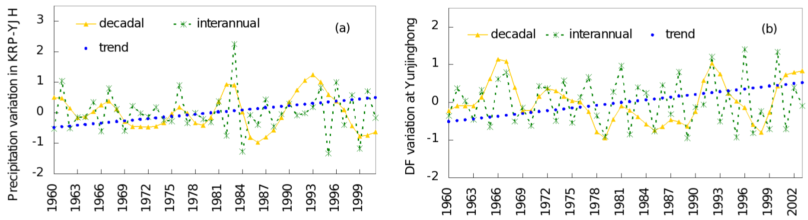

Figure 12.9: The trend, inter-annual and interdecadal variations of DF at Yunjinghong hydrological site (a) and MDP in KRP-YJH (b) (standardized value)

corresponding KRP. Especially after 1993, influence of the precipitation change on DF variation at Gajiu hydrological site is more significant than that of DF variation in the midstream, so the DF variation at Gajiu hydrological site shows different trend from that in the midstream.

Yunjinghong hydrological site

The multi-timescale characteristics of the DF at Yunjinghong hydrological site and MDP in KRP-YJH are displayed in figure 12.9.

According to the patterns of trend, inter-annual and interdecadal variation of MDP in KRP-YJH (figure 12.9.a), the MDP exhibits remarkable ascending trends from 1966 to 1992 and declining trends after 1993. Accompanying with that, the DF variation at Yunjinghong hydrological site exhibits similar features with the MDP but different features from that at Jiuzhou hydrological site in the midstream (figure 12.9.b).

Based on the real part of wavelet transform coefficients for the MDP in KRP-YJH (figure 12.10.a), it can be noticed that the MDP variation in KRP-YJH exists in 13 year, 8 year and 2 year periodic oscillation cycles. According to squared module pattern (figure 12.10.b) of wavelet transform coefficients of the MDP, it can be further inferred that stable 13 year cycles exist in the periodic oscillation of the MDP during 1960~2001. With regard to the inter-annual oscillation cycles of the MDP, they change around 1985, with stable 8 year cycle existing before 1985 and stable 2 year cycles occurring after 1985.

The periodic oscillation pattern of the DF at Yunjinghong hydrological site is displayed in figure 12.11, exhibiting 2 year, 3 year, 4 year, 5 year and 9 year oscillation cycles. As shown in figure 12.11.b, the interdecadal evolution of stable 9 year cycles existed for 40 years, while the inter-annual oscillation cycles also change around 1985: stable 5 year and 3 year oscillation cycles existed before 1985, and then turn to 2 year and 3 year oscillation cycles after 1985.

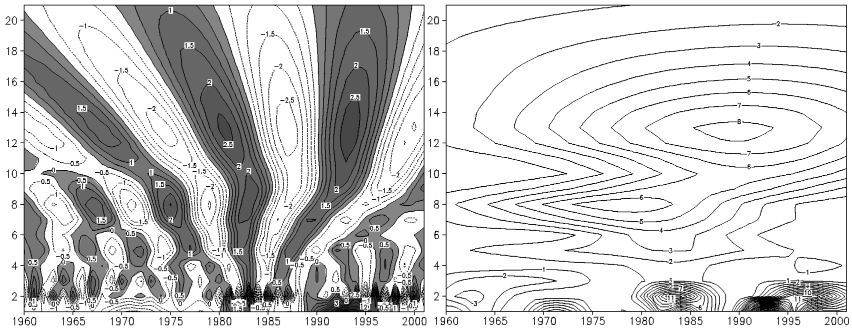

Figure 12.10: Wavelet transform coefficients of the MDP in KRP-YJH (1960~2001)

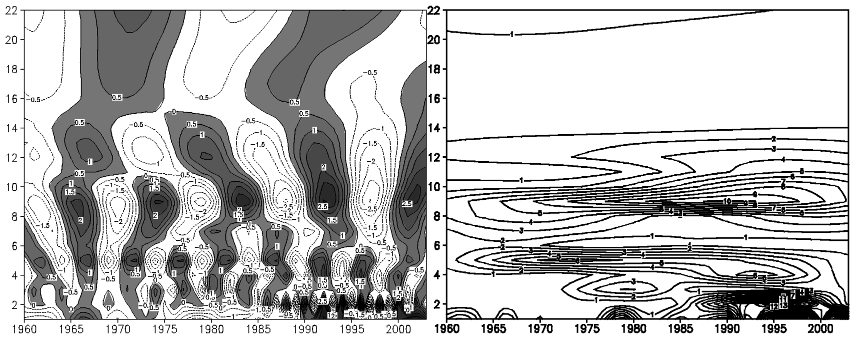

Figure 12.11: Wavelet transform coefficients of the DF at Yunjinghong hydrological site (1960~2003)

According to the above analysis, the variations of DF at Gajiu and Yunjinghong hydrological sites in the downstream are in accordance with precipitation variation in KRP and DF at Jiuzhou hydrological site in the midstream in most years before 1995. After 1996, however, the DF variation at the two hydrological sites in the downstream exhibit different trends from that at Jiuzhou hydrological in the midstream due to the influence of DP in corresponding KRP, especially during 2001~2003. It means that, the DF variations in the downstream are not only influenced by the DF variation in the midstream, but also precipitation in corresponding KRP. Especially after 1995, the influences of precipitation variation on DF variations at the two hydrological sites in the downstream are more significant than that of the DF in the midstream. Considering the former researches [19, 22, 24], it can be confirmed that the construction of the Upper Mekong hydropower stations has little influences on the DF variation in the downstream during 1995~2003, and the precipitation variation leads to the DF variations' inconsistent trends between midstream and downstream.

CONCLUSION

1. There is no significant correlation between the DF and DP variation in the up-midstream, which means the DP has little influence on the DF variations, and the latter are mainly controlled by the supplement variation of groundwater and snow melting. The distributions of KRP-GJ and KRP-YJH in the downstream are mainly from the north to the middle part of Yunnan Province, with larger area in the KRP-YJH.

2. The DF variations in the downstream are influenced by not only the DF variation in the midstream, but also precipitation in corresponding KRP. Especially after 1995, the influences of precipitation variation on DF variations at two hydrological sites in the downstream are more significant than the DF variation in the midstream, so the DF variation in the downstream exhibits similar features with the MDP in corresponding KRP but different features from that in the midstream.

3. The DF in upper, middle, and lower reaches of UMR mainstream significantly increase before middle 1960s, and decrease during 1965~1972; From 1973 to 1980, the DF variations at Changdu, Jiuzhou, and Gajiu hydrological sites show remarkable ascending trends, but turn to remarkable declining trends at Yunjinghong

hydrological site (the last national basal hydrological site before UMR flows out of China). The DF at the four hydrological sites increases first then decreases later during 1980~1992, and show decreasing trends during 1993~1995. During 1996~1998, the DF ascends in the midstream but declines in the downstream. After 1998, the DF variations in the downstream exhibit gradual increasing trends but gradual decreasing trends in the midstream.

4. The periodic oscillation of DF in the upstream shows stable 5 year, 9 year and nearly 15~16 year oscillation cycles; The DF in the midstream shows stable 13 year evolution cycles, but its interannual oscillation cycles change around 1975 and 1985. Due to the influence of precipitation variation, the DF variation at Gajiu hydrological site shows different periodic oscillation from Jiuzhou hydrological site in the midstream after 1993. The periodic oscillation of the DF variation at Yunjinghong hydrological site shows similar features with that in the midstream, changing around 1975 and 1985.

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13

INTERDECADAL VARIATION OF EXTREME PRECIPITATION EVENTS IN FLOOD SEASONS OVER LOW-LATITUDE HIGHLAND - THE UPPER MEKONG

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ABSTRACT

This is a study to analyze the spatial distribution and interdecadal variation of extreme precipitation events across the low-latitude highland over the past 50 years, based on the daily precipitation data collected by 94 weather stations in the Yunnan Province during the flood seasons of 1961-2008. The relationship between the interdecadal variation of extreme precipitation events and atmospheric circulations is also examined in a preliminary manner using NCEP/NCAR's reanalyzed atmospheric circulation data over the same period. Results indicate that extreme precipitation events which occurred in the flood season over the low-latitude highland areas are spatially distributed in a U-shape, in the context of mean climate variation, with most extreme precipitation events appearing in the west, south, and eastern parts of the low-latitude highland areas. Extreme precipitation events that occurred over the flood season has exhibited noticeable interdecadal variations, not only in the context of total occurrences, but also in the context of the density of occurrences. The 1960s, and the period from the end of the 20th century to the early 21st century, marks the active period of extreme precipitation events, with the 1970s and the early 1990s having less active periods. The former had at least one more occurrence, compared with the latter, in terms of extreme precipitation events. The former has registered an annual frequency of 13.0% and 4.4% for 15-20 station/time and 20 station/time respectively, with the latter sitting at 0% for the same frequency. The combination of abundant water vapor (fed into low-latitude highlands by strong Indian summer monsoons

and East Asian summer monsoons) and the cold air from the northwest part of low-latitude highlands is a major driver behind the increased occurrences of extreme precipitation events in the flood season over low-latitude highland areas.

INTRODUCTION

Extreme precipitation events have attracted much attention on the serious impacts left behind, especially on the possible evolutions and trends of extreme precipitation events in China. Tao and Ding (1981) examined the distribution of rainstorms in China, pointing out that China had its rainstorms mainly in the south, Yangtze River Valley, and the north. Matsumoto and Takahashi [1999] indicated in their study that in the summer season, Japan, the Republic of Korea, and the Yangtze River and Huaihe River Valleys were areas which had the most occurrences of monsoon storms. P. M. Zhai et al [1999] studied the variation in trends of extreme precipitation values in China, and believed that the areas having extreme rainy days were narrowing down in scope, though the areas that have extreme precipitation intensity (on average) were expanding. Wang and Zhou [2005] demonstrated that extreme precipitation events had an ascending trend of 10%-20% every decade across the Yangtze River Valley. Zhai et al [2005] pointed out that the west, the lower and middle reaches of the Yangtze River, the southwest, and the southern coastal areas have witnessed noticeably increased occurrences in extreme precipitation events, though the north and Sichuan Basin saw a descending trend for the same events. In recent years, M. Bao et al [2006, 2007] investigated the interdecadal variation of rainstorms and the spatial/temporal distribution of sustained rainstorms in China, and found that summer storms that occurred in the eastern part of the country were closely associated with the floods that appeared in the same region. For example, rainstorms that occurred in the Yangtze and Huaihe River Valleys had a noticeably increased contribution to the floods in the valleys in the 1990s. In China, most sustained local rainstorms occurred in the summer, especially in June. Geographically, the south of the Yangtze River and the southern part of China had the most occurrences of rainstorms. In the southern part of the Yangtze River, most sustained rainstorms occurred in June. In the southern part of China, the sustained rainstorms either occurred before the flood season (South China type), or after the flood season (South China depression type).

Physically located in the southwest part of China, the low-latitude highland enjoys a unique environment featuring the Bay of Bengal to the south, and two tropical oceans and the Qinghai-Tibet Plateau in the northwest. The sophisticated terrains, plus the visits of Indian and East Asian monsoons in the summer, has complicated the spatial and temporal distribution of extreme precipitation events during the flood season over the low-latitude highland, making it distinct from other regions in the country. Unfortunately, previous studies consider little about the relationship between the spatial and temporal distribution of extreme precipitation events in the flood season over the highland areas and large-scale circulations. This paper analyzed the inner relationship between the spatial distribution of the interdecadal variation of extreme precipitation events over the low-latitude highland during the summer season (May-October) and large-scale circulations, based on daily precipitation data and previous studies, in an attempt to provide scientific evidence for extreme precipitation events related to disaster prevention and preparedness of decision making, to reduce the losses caused by extreme precipitation events.

DATA

Precipitation data employed in this study were provided by the Yunnan Climate Center. They were the daily precipitation data collected by 94 weather stations over the low-latitude highland in the Yunnan Province during the flood season (May-October) of 1961-2008. Atmospheric circulation data was reanalyzed data provided by the NCEP/NCAR for the same period of time. The data physically employed in the study were the daily precipitation data collected by 94 weather stations in the summer period (May-October) from 1961 to 2008, with the missing data stations removed. Daily precipitation data of larger than 25mm were chosen. A statistical analysis was also performed to understand the inner relationship between the spatial and temporal distribution of extreme precipitation events and atmospheric circulations.

RESULTS AND ANALYSIS

Climate features behind extreme precipitation events

The low-latitude highland areas investigated enjoy a distinct monsoon climate featuring abundant rainfall in the summer season. From figure 13.1 it can be seen that the spatial distribution of the days of multi-year

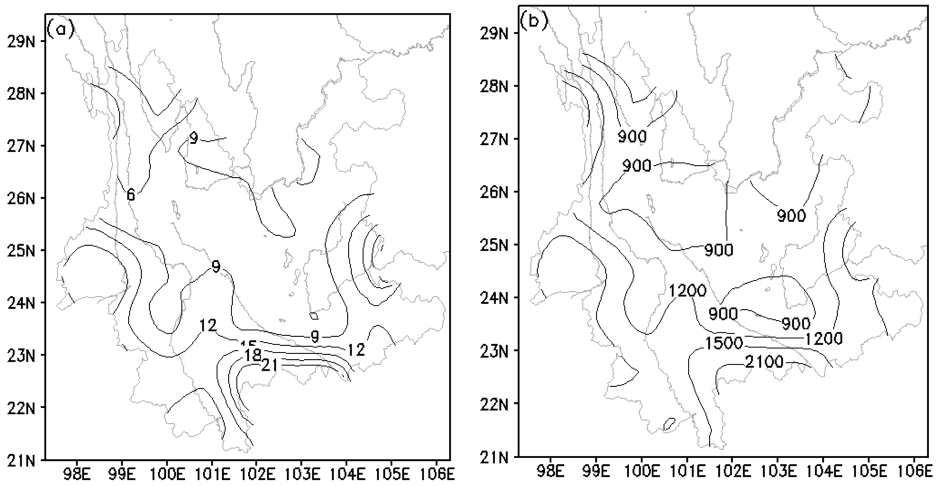

Figure 13.1: Spatial distribution of averaged days of extreme precipitation events (1a) during the flood season of 1961-2008, and annual precipitation (1b) over the low-latitude highland areas

averaged extreme precipitation events agreed with the spatial distribution of annual rainfall during the flood seasons over the same areas, showing an ascending trend from north to south. The same areas saw the least occurrences of extreme precipitation events in the northwest, with multi-year averaged days of extreme precipitation events being less than 6 d a-1. The Deqing Station was at the bottom at only 2 d a-1. The middle and northeast part of the areas registered multi-year average days of extreme precipitation events at 6-9 d a-1. The remaining part of the areas sat in a range between 9 d and 15 d a-1, with the Nu River, Lancang River, and the lower reach of Red River being the high-value areas. The Jinping Station was on the top at 25 d a-1. Corresponding to the spatial distribution of multi-year average annual precipitation and the days of extreme precipitation events, the low-value areas sat in the northwest, with an annual precipitation less than 900mm, and the high-value areas stood in the Nu River, Lancang River, and the lower reach of Red River, enjoying an annual precipitation exceeding 1,200mm; with the top value appeared at the Jinping Station to 2,318mm. It is interesting to note that the spatial distribution of extreme precipitation events over the low-latitude highland had a correlation coefficient of 0.83 with the spatial distribution of annual precipitation that has passed a significant test of $\alpha = 0.001$, suggesting a close relationship between the two.

Figure 13.2a shows the single peak distribution of multi-year averaged days of extreme precipitation events in the flood season. Unlike

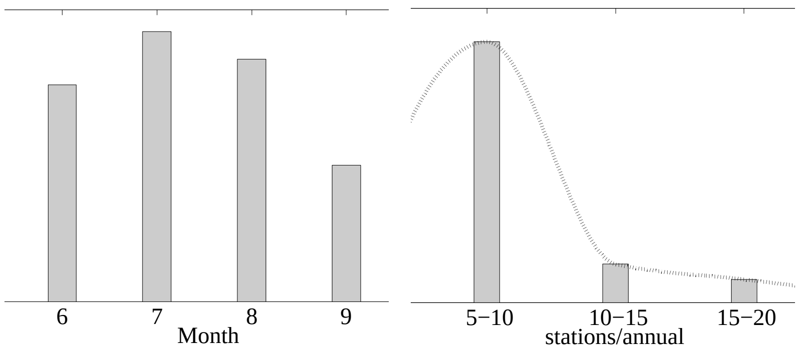

Figure 13.2: Averaged monthly and seasonal distributions of extreme precipitation events (a), and density distribution (b) over the low-latitude highland areas (1961-2008). Dashed lines in (b) represent the simulated values.

the Yangtze and Huaihe River Valleys where the peak of extreme precipitation events appeared in June, the low-latitude highland areas had its peak mainly in July at 231 station/time, followed by August and June at 207 station/time and 186 station/time respectively. The rest of the months in the year registered a reduced peak time, though remaining at 70 station/time or above the average. Figure 13.2b also presents a single peak distribution of extreme precipitation events in the flood season in terms of the density, with a 70.8% frequency for 5-10 station/time, followed by 10.4% for less than or equal to 5 station/time, or 10-15 station/time. Frequency rates larger than 20 station/times was the lowest at only 2.1%.

Interdecadal variation of extreme precipitation events

Figure 13.3 indicates that the interdecadal variation of extreme precipitation events ran counter against the results derived from reference [6] on north China and the Yangtze River Valley. The smoothed average of extreme precipitation events in year 11 and the smoothed average curves in year 21 split the temporal evolution of extreme precipitation events into three phases, namely before 1969 and after 1995, characterized with more extreme precipitation events, and the period from 1970 to 1994 featured with the reduced occurrences of extreme precipitation

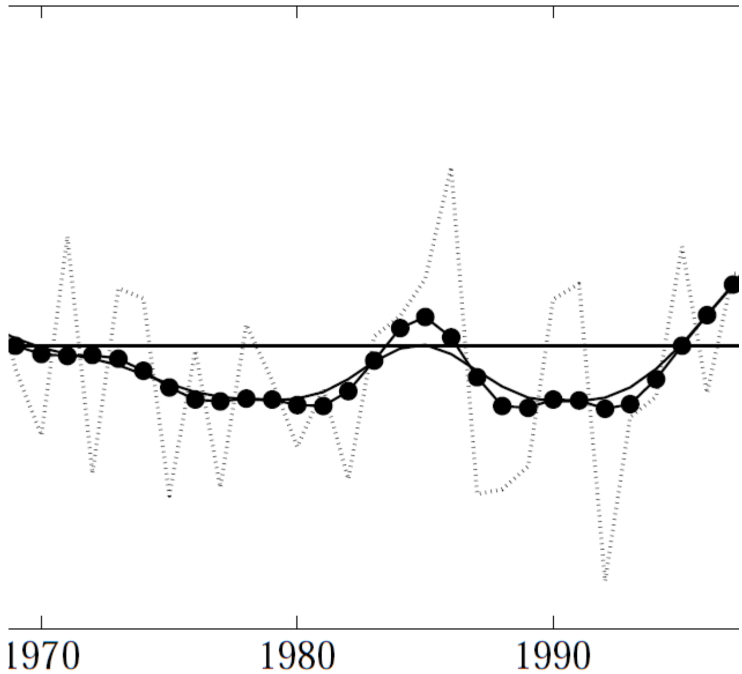

Figure 13.3: Standardized time series of extreme precipitation events. Dashed lines represent the observed values, circled solid lines the smoothed averages for year 11, and solid lines the smoothed average for year 21.

events. In this context, the interdecadal variation of extreme precipitation events has to be analyzed based on the combination of two phases featured with more extreme precipitation events, namely 1961-1969 and 1995-2008.

Figure 13.4 shows that most part of the low-latitude highland, except some areas in the lower reaches of Lancang River, some part of the Yuan River and Red River, and some areas in the Nanpan River Valley, registered at least one more event in the period where more extreme precipitation events occurred, compared with other areas which have less occurrences. The result passed the significance test at $\alpha = 0.01$, suggesting that the interdecadal variation of extreme precipitation events had a fine consistency in spatial distribution.

One can see from figure 13.5a that whether in a period having more extreme precipitation events, or in a period having less, the monthly distribution of extreme precipitation events shared a similar pattern with mean climate variations, dominated by a single peak. Both had their peaks in July. However, the active period is somewhat different from the less active period in the monthly distribution of extreme precipita-

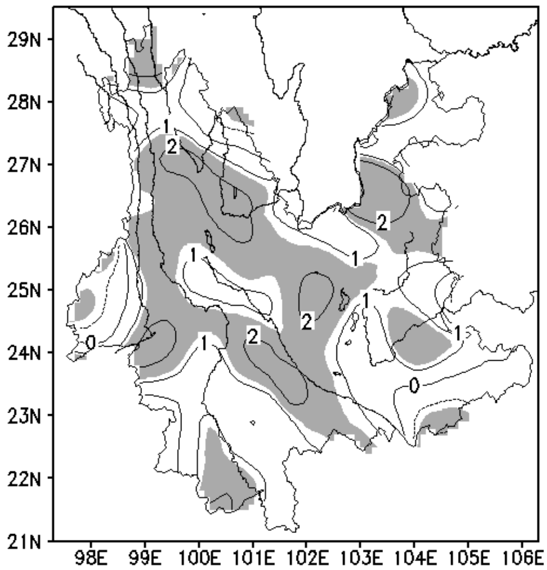

Figure 13.4: Distributions of the active and less active periods. Shadowed area means a significance test of $\alpha = 0.01$ was passed.

tion events. For example, the frequency of extreme precipitation events in the active period, including May where the rainy season started, and flood-prone July and August, was higher than in the less active period. August cut out the largest difference by 26 station/time more in the active period, compared with the less active period. One can see from figure 13.5b that the density of extreme precipitation events in the flood season also showed a single peak distribution in both active and less active periods, with an average peak at 5-10 station/time/year. However, the density in the active period was noticeably different from the one in the less active period. The less active period was heading for a frequency of 10-15 station/time a year, with the year having the frequency of 10-15 station/time reaching as high as 88.0%, and the frequency for 5-10 station/time at zero. Meanwhile, the active period became flat in the distribution of frequency, with the highest frequency remaining at 5-10 station/time, though noticeably lower, compared with the less active period, at only 52.2%. In the remaining months of the year, the frequency of extreme precipitation events also ran higher, compared with the less active period, with 13.0% and 4.4% for 15-20 and 20 station/time respectively.

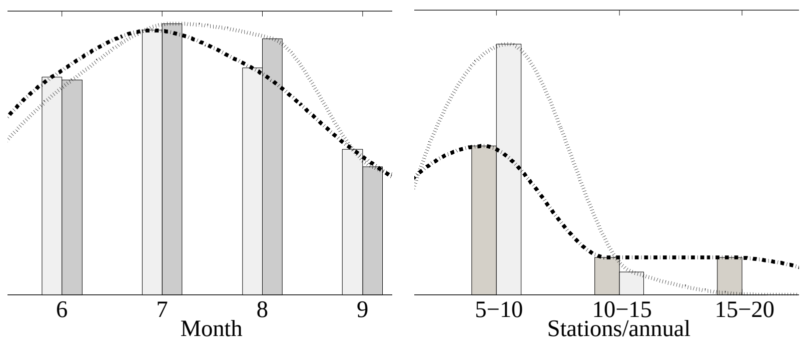

Figure 13.5: Monthly and seasonal distributions of extreme precipitation events in the active and less active periods (a), and density distribution (b). Dashed lines and dot dashed lines are the simulated values. White bars represent the less active period, and the gray one the active period.

Relationship between the interdecadal variation of extreme precipitation events and atmospheric circulations

Previous studies of interdecadal global climate variation showed that global climate had witnessed a noticeable interdecadal variation in the mid 1970s (Thompson et al., 1998, 2000, 2001; Wallace et al., 2000; D. Y. Gong et al, 1998, 1999, 2002; J.H. Zhu et al, 2003; K,D, Fan et al, 2004, 2006; Wang et al., 2001, 2005; D. P. Jiang et al, 2005; M. Bao et al, 2006). However, one can see from figure 13.3 that the interdecadal variation of extreme precipitation events, which occurred across the low-latitude highland areas indicated a noticeable difference from the interdecadal variation of global climate. In this context, it is necessary to analyze the large-scale circulation background against which the interdecadal variation of extreme precipitation events arose. Figure 13.6 shows that there was a close tie between extreme precipitation events and atmospheric circulations. The active period of extreme precipitation events corresponded to the Somali cross-equatorial flow and the cross-equatorial flows in the Philippines and the northern part of Australia that were stronger than the one in the less active period. This suggests that the abnormally strong Indian monsoon and the abnormally easterly and westerly positioning of the west pacific subtropical high would feed more water vapor into the flood season over the low-latitude highland areas either from the Bay of Bengal or from South China Sea, which in turn triggered upwards, the frequent occurrences of extreme precipitation events in the flood season over the areas. The exponential showing the intensity of Indian summer monsoon circulations, namely

$IMI = U_{850}\left(5-15^0N, 50-110^0E\right) - U_{200}\left(5-15^0N, 50-110^0E\right)$

and DI that indicates the intensity of east Asian summer monsoons,

$DI = Div_{850}\left(10-15^0N, 105-120^0E\right) - Div_{200}\left(10-15^0N, 105-120^0E\right)$

produced a correlation coefficient at 0.30 and 0.25 respectively for extreme precipitation events (Webster et al., 1992; Li et al. 1999). Both of them have passed significance test at $\alpha = 0.05$ and $\alpha = 0.10$ respectively. Where U_{850}, represents zonal winds at 850 hPa, and U_{200} the same winds at 200 hPa. Div_{850} shows the divergence at 850 hPa, and Div_{200} the same indicator at 200 hPa. The abnormal distribution of local wind fields in the active and less active periods indicate that the former had a stronger north-westly wind, compared with the latter, implying that under a rich water vapor supply, the cold air stemmed from the northwest part of the low-latitude highland areas became a major contributor to the frequent occurrences of extreme precipitation events. The combination of cold air and water vapor explained the fundamental cause of frequent occurrences of extreme precipitation events.

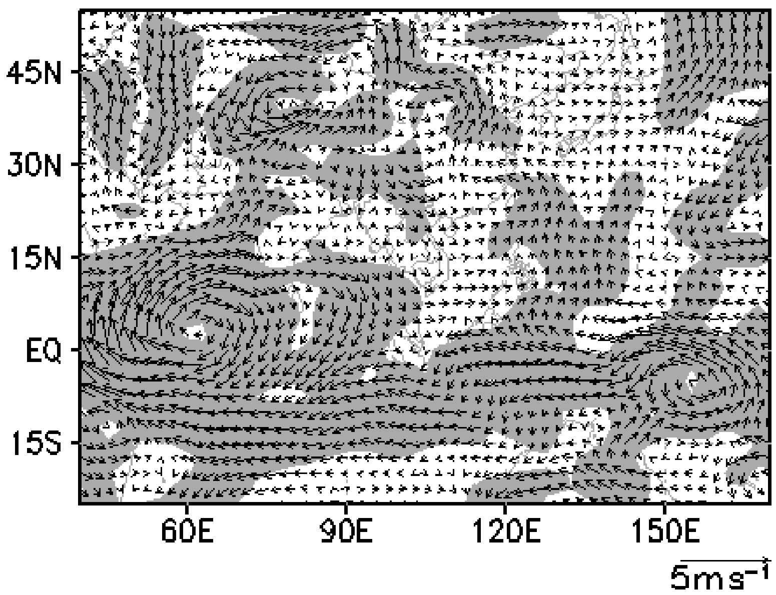

Figure 13.6: Circulations at 700 hPa during the active and less active periods. Shadowed areas are the one that have passed significance test at $\alpha = 0.05$.

This study analyzed the interdecadal spatial and temporal variations of the extreme precipitation events that occurred across the low-latitude highland areas, based on the daily precipitation data collected by the low-latitude highland weather stations during the period of 1961-2008. The following conclusions have been derived from the study:

1. The extreme precipitation events occurred in the flood season over the low-latitude highland had a spatial distribution of mean climate variations that agreed with a U-shaped spatial distribution of annual total rainfall, with most extreme precipitation events appearing in the west, south, and eastern parts of the low-latitude highland areas. July had the most occurrences of extreme precipitation events.

2. Extreme precipitation events that occurred in the flood season over the low-latitude highland showed a noticeable interdecadal variation, with a fine consistency in the spatial distribution. The 1960s and the period from the end of the 20^{th} century to the early 21st century marked an active period for extreme precipitation events, with the 1970s and the early 1990s being the less active period. The former registered at least one more occurrence, compared with the latter, in terms of extreme precipitation events.

3. The interdecadal variation of extreme precipitation events occurred in the flood season over the low-latitude highland found its expression not only in the total occurrences, but also in density. The former had at least one more occurrence, compared with the latter, in terms of the occurrence of extreme precipitation events. The active period had an annual frequency of 13.0% and 4.4% for 15-20 station/time and 20 station/time respectively, with the same occurrences in the less active period sitting at 0%.

4. Author discussed the circulation background behind the interdecadal variation of extreme precipitation events in a preliminary manner, namely the combination of the abundant water vapor supply to the low-latitude highland, fed by strong Indian summer monsoons and east Asian summer monsoons, and the cold air that stemmed from the northwest part of the low-latitude highland explained the fundamental cause of the frequent attacks of extreme precipitation events in the flood season over the low-latitude highland.

ACKNOWLEDGMENTS: This study was supported by the National Natural Science Foundation of China under grant numbers U0933603 and Natural Science Foundation of Yunnan Province 2009CC002.

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14

OPERATION OF HYDROPOWER SYSTEM IN LA NGA RIVER BASIN, VIETNAM WITH ENVIRONMENTAL FLOW CONSIDERATION

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ABSTRACT

The study deals with the operation of hydropower system in La Nga River Basin, Vietnam to assess the implication of maintaining the natural flow regime on hydropower production. The system is analyzed with different operating policies and the alteration in the natural flow regime in the river is evaluated using the indicators of hydrologic variations based on the Range of Variation Approach (RVA). A tradeoff is obtained between the hydropower production and the environmental flow needs. The study results indicate that, with suitable changes in the operation, the downstream flow regime can be improved maintaining the hydropower production level.

INTRODUCTION

The operation of reservoir results in alteration of the flow regime downstream. This in turn may cause damage to the aquatic ecosystems prevailing in the river basin. The concept of maintaining a minimum flow for maintaining the ecosystem in the river basin, known either as environmental flow or ecological base flow, has gained importance in the recent years. An environmental flow is the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated. The idea of environmental flows to maintain the natural flow regime of the river started gaining importance since 1990s. Poff et al (1997) have stressed that maintaining the natural flow regime is essential in sustaining native biodiversity and ecosystem integrity in river basins. This concept of maintaining the natural flow regime has resulted in a shift from the earlier emphasis on maintaining a minimum flow downstream.

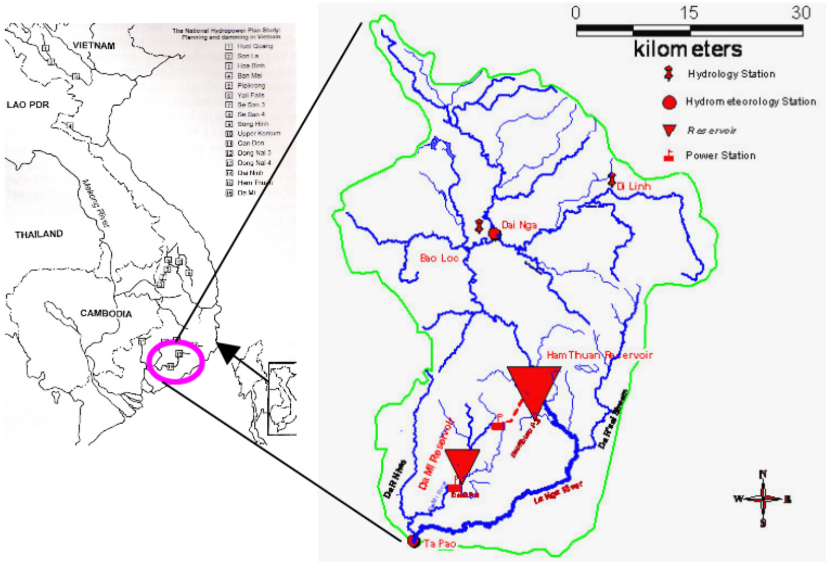
Most of the reservoir operation studies reported in the literature did not explicitly consider the environmental flow requirement. In one of the earlier studies, Palmer et al (1982) showed the implication of environmental flow consideration on the yield of a reservoir. Flug and Ahmed (1990) proposed a methodology to quantify and characterize different preferred flow regimes. Cardwell et al (1996) developed a multi-objective optimization model to study the tradeoffs between fish population capacity and water shortage levels. Shirakawa and Tamai (2003) proposed a subsidy system for setting environmental flow release from hydropower stations. They developed a benefit function for environmental flows as a function of flow rate. Using this benefit function they estimated the possible subsidy to be paid to compensate the power production loss due to environmental flows. Richter and Thomas (2007) outlined a number of ways in which dam operations, water use systems and land management can be modified to restore the environmental flow regime.

The study reported herein deals with the operation of Ham Thuan and Da Mi Hydropower System in La Nga River Basin, Vietnam to understand the impact of maintaining the natural flow regime on hydropower production. Through different scenario analysis, the objective is to propose a reservoir operation policy with a trade-off between energy production and environmental flow requirements.

STUDY AREA

The La Nga River is one of the main tributaries of Dong Nai River in Central Vietnam. The Ham Thuan reservoir is on the middle course of La Nga River which receives water from two principle tributaries, Darnga and Dariam. The Da Mi reservoir located on Da Mi River is on the downstream of Ham Thuan reservoir. Figure 14.1 shows the location map of La Nga River Basin along with Ham Thuan and Da Mi reservoirs. The installed capacity at Ham Thuan hydropower plant is 300 MW while that of Da Mi hydropower plant is 175 MW.

The Da Mi dam is essentially a runoff-the-river type structure with a storage capacity of 11.6 million m^3. The water release from the Ham Thuan power plant is diverted to the Da Mi reservoir and the same water is used twice for power generation. The catchment area of Ham Thuan is 1280 Km^2, while that of Da Mi is 83 Km^2. The storage capacity



La Nga River Basin

Figure 14.1: Location Map of La Nga River Basin

of the Ham Thuan and Da Mi reservoirs are 695 and 140.8 million m^3, respectively. The average annual inflow to Ham Thuan reservoir is 1598.9 million m^3. The average annual outflow from Ham Thuan going as inflow to Da Mi is 1570 million m^3 while the average annual inflow to the reservoir from the catchment area of Da Mi is 110 million m^3. With this system of operation, the flow in the downstream section of the La Nga River is reduced drastically.

ASSESSMENT OF ENVIRONMENTAL FLOWS

Tools and methods developed for assessing the environmental flow requirements can be grouped into four broad categories, namely, hydrologic index methods, hydraulic rating methods, habitat simulation methods and holistic methods. In this study the Range of Variation Approach (RVA) is used for assessment of environmental flow requirements. This approach, developed by Richter et al (1998), is a river reach or river basin scale approach that establishes target flows for river management according to the natural (unimpaired) hydrologic regime in a river system. The RVA provides a range of hydrological criteria that the reservoir operations should achieve (Suen and Eheart, 2006).

Indicators of Hydrologic Alteration (IHA) software (The Nature Conservancy, 2007) is used for calculating the natural and altered flow regimes. The daily flow data series from 1977 to 1999 is used as input data to assess the natural flow regime before the construction of the dam. While, the daily flow data from 2002 to 2005 is used to assess the flow regime after the construction of the dam. The 32 ecologically relevant hydrologic attributes as suggested by Richter et al (1998) are used to evaluate the hydrological alteration.

The median values of each of the 32 attributes are calculated for both pre-dam and post-dam series. As the flow target has not been set up for La Nga River as well as the ecological information was inadequate, the initial RVA target range for each parameter was considered within the 25- and 75-percentile values of pre-dam daily flow as suggested by Richter et al. (1998). The degree of hydrologic alteration (D), as a measure to quantify the deviation of the post-dam flow regime from the pre-dam one is defined as:

$$D = \left[\frac{N_0 - N_e}{N_e}\right] \times 100\% \tag{14.1}$$

In equation (14.1), N_0 is observed number of post-dam years for which the value of the hydrologic parameter falls within the RVA target range; and Ne expected number of post-dam years for which the parameter value falls within the RVA target range. Richter et al. (1998) further suggested that the value of D ranging between 0 and 33% represents little or no alteration (low alteration), 33–67% represents moderate alteration, and 67–100% represents high alteration. In addition, a single integrated index that presents the overall hydrologic alteration was suggested as the average value of 32 degrees of alteration.

The flow condition at Ta Pao gauging station, located 10 km downstream of the Da Mi reservoir is used to assess the flow regime and the hydrological alteration in the river due to the operation of the hydropower system. The HEC-5 software (USACE, 1998) is used to simulate the operation of the reservoir system with the daily flow data from 2002 to 2007. Five alternate scenarios with different operating policies are considered for analysis. Based on the simulation results, the altered flows at Ta Pao gauging station are computed and the degree of hydrologic alteration is determined for each scenario. Results of different scenarios are discussed in the following section.

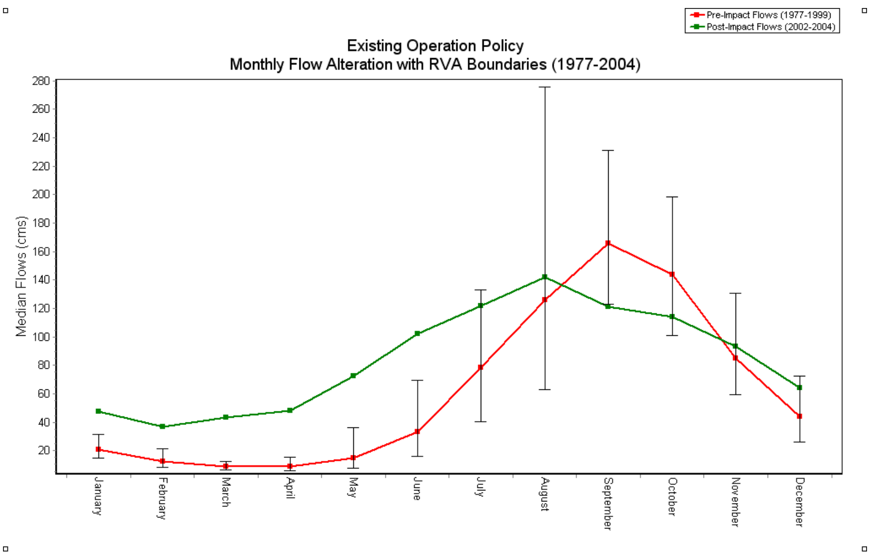


Figure 14.2: Median Monthly Flows at Ta Pao Gauging Station for Pre-dam and Post-dam Condition in Scenario 1

RESULTS AND DISCUSSION

In Scenario 1, the Ham Thuan and Da Mi reservoir operations are simulated based on the existing policy for the period of 2002 to 2005. The median monthly flows at Ta Pao gauging station for this post-dam situation compared with the pre-dam median monthly flows (for the period of 1977 to 1999), shown on figure 14.2, indicates significant change in flow regime subsequent to dam construction. The monthly median flow is more during the post-dam period except in the month of September and October. The RVA target ranges with respect to pre-dam median monthly flows are indicated in this figure by whiskers. Most of the monthly mean flows fall out of RVA target range except during the month of July, October, and November, with their degree of hydrologic alteration ranging from 54 to 100%. Out of 32 ecologically relevant hydrologic parameters, 7, 4 and 21 parameters are in low, moderate and high degree of alteration, respectively; and the average degree of hydrologic alteration is 74% which belongs to high degree of alteration. In this operational scenario, the total power generation is 5189.5 Gigawatt hour (GWh) with 3389.8 GWh from Ham Thuan power plant and 1799.7 GWh from Da Mi power plant. Scenario 1 is used as the base case for comparing the outcome of other scenarios.

In Scenario 2 both power plants are run with full capacity. The total energy production is increased by 8%, with 2% increase from Ham Thuan power plant and 20% increase from Da Mi power plant. In this scenario, out of 32 ecologically relevant hydrologic parameters, 10, 14 and 8 parameters are in low, moderate and high degree of alteration, respectively; and the average degree of hydrologic alteration is 50% which indicates a moderate alteration.

In Scenario 3, the operation of the hydropower system is simulated based on the existing operating policy to optimize the power production from the Ham Thuan reservoir. A non- linear optimization model is applied to maximize the power generation at Ham Thuan reservoir with maximum storage capacity at Da Mi reservoir as a constraint. Da Mi hydropower system is a runoff-the-river plant and its power production depends on Ham Thuan outflow. Maximum power production from Da Mi hydropower plant is achieved by operating both power plants following the existing operating policies. The overall energy production is increased by 5% compared to the energy production under existing operating condition, Scenario 1. The increase in power production at Ham Thuan is 1%, while that at Da Mi reservoir is 14%. The numbers of ecologically relevant hydrologic parameters in low, moderate, and high degrees of alteration are 10, 4, and 18, respectively; and the average degree of hydrologic alteration for this case is 65% indicating a moderate alteration.

For Scenario 4, the hydropower system is operated maintaining the flow at Ta Pao gauging station within a specified RVA target range. The operation of the system is simulated with specification of all flow parameters at Ta Pao fixed at 50 percentile of the RVA target range. The power production at Ham Thuan reservoir site is increased by 1% when compared to the production under existing operating policy. The increase at Da Mi reservoir is 10%, while the overall increase is 4%. The degrees of alterations of various RVA parameters are computed and the numbers of parameters categorized under low, moderate, and high degree of alteration are respectively 8, 18, and 6. The average degree of hydrologic alteration for this case is 47% and this represents a moderate alteration.

For Scenario 5, Ham Thuan reservoir is operated for maximum power generation within the existing rule curve and the Da Mi reservoir is operated to trade off the two objectives: generating energy and meeting the environmental flow requirement. To satisfy these objectives, Da Mi reservoir is operated so that the total amount of water released through spillway is at minimum possible while the overall degree of hydrologic alteration at Ta Pao location is at moderate alteration. With this condition, the power production at Da Mi reservoir is decreased by 34% compared to Scenario 1 of power production under existing operating policy and the power production at Ham Thuan reservoir is increased by 1%. However the overall power production is reduced by 11% compared to the base case of operation with existing operating policy (Scenario 1). For this scenario, the numbers of RVA parameters coming under low, moderate, and high degrees of alteration are 16, 6, and 10, respectively and the average degree of hydrologic alteration for this case is 45% belonging to moderate alteration.

The results of simulation for the five alternate scenarios are summarized in table 14.1. With the existing operation policy the natural flow regime is altered significantly with the average degree of hydrologic alteration being 74% (Scenario 1). Scenario 2 gives the highest power production and the overall degree of hydrology alteration is at moderate alteration level. The degree of hydrologic alteration in the natural flow is lowest at 46% in Scenario 5. However, this decrease in hydrologic alteration is achieved with 11% decrease in overall power production. On the other hand, the Scenario 4, when the flow parameters at Ta Pao site are kept at 50 percentile of the target RVA range, provides the best outcome among all the scenarios. The overall hydrologic alteration is 47%, one percent more than the lowest found for Scenario 5. However, the power production in this case is increased by 4% compared to the power production with the existing policy. Also, the power output is only 4% less than the maximum power produced under Scenario 2, in which case the average degree of hydrologic alteration is 50% indicating a moderate alteration. For details of analysis and results reference can be made to Chien (2007).

CONCLUSIONS

The operation of the reservoir system with the existing policy results in significant alteration in natural flow regime as indicated by the average degree of hydrologic alteration of 74% being in the high alteration range. With Ham Thuan reservoir operated for maximum power generation (within the existing rule curve) and the Da Mi reservoir operated to trade off the two objectives of generating energy and meeting the environmental flow requirements, the overall power production is reduced by 11% compared to the production under existing operating policy. However, when the hydropower system is operated under a specified RVA target of moderate level of alteration, the overall hydropower production is increased by 4%. This clearly indicates that the hydrologic alteration of the natural flow regime can be reduced without signifi-

Scenario	Simulated power production (MWh)	No. of Parameters			Overall degree of alteration (%)	Discharge at TaPao (m3/s)		
		L	M	H		Min	Ave.	Max
1	5,131,601	7	4	21	74	1.8	83.6	354.3
2	5,616,357	10	14	8	50	4.1	88.7	414.3
3	5,472,925	10	4	18	65	0.3	84.0	406.2
4	5,409,526	8	18	6	47	8.0	88.2	511.5
5	4,731,157	16	6	10	46	6.2	83.8	552.6

Table 14.1: Summary of Results of Reservoir Operation for Different Scenarios

cantly affecting the power production by making suitable changes in operation.

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15

RECENT FLOOD OF THE MEKONG RIVER DELTA AND THEIR IMPACTS FOR AGRICULTURE

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INTRODUCTION

The Lower Mekong Delta is one of the most important regions for economic development in Vietnam. The delta provides significant agricultural production and has abundant resources including agriculture, fisheries, wetlands, and forestry. The flooded area of the delta is estimated at 1.8 million ha during peak flood season, with floods usually lasting six months and at inundation depths of 4.0 m. Flooding has induced serious negative impacts on agricultural production and on the lives of urban residents. Southwest monsoons, typhoons and tropical depressions are prolonged, causing torrential rainfall and low pressure areas in the northern part of the Eastern China Sea which in turn leads to heavy precipitation in the delta.

The flood season from July to December occurs later than the flood season upstream of the delta. In the dry season, the delta is affected strongly by salinity intrusion and tidal effects, causing the disturbance of agricultural production. Inhabitants of the delta have modified the natural environment using agricultural engineering measures, and have adapted their economic activities to the special conditions that prevail in the physical geography; in particular, they have learned how to adapt to the floods. Agriculture production is also increasing the severity of next-year's floods.

FLOOD PEAK VARIATION IN THE LOWER MEKONG RIVER

Based on the observed maximum water level data from 1961 to 2004, the flood of year 2000 was the highest ever recorded at Chau Doc observation station and the second highest recorded at Tan Chau observation station since 1961 in Vietnam. Hydrographs of remarkable flood years since 1961 show that incidences of extremely high floods occurred early during the consecutive years of 2000, 2001, and 2002. All had reached peaks of greater than 4.7 m at Tan Chau. The year 2000 flood was a historical flood for the lower Mekong River Delta. Comparisons of maximum water levels reached during remarkable flood events at various stations in the Mekong River Delta show that recently, flood water levels reached its highest point at almost all stations in the Vietnamese part of the Mekong River Delta, even though floods upstream were not at their highest point.

The ratio of flood discharge flowing into the lower Mekong River channel reached its maximum water level in 1963, with flows into the Bassac, one of the tributary rivers reaching its maximum water level in 1996. The ratio of flood flow in to the Mekong River was larger than average. For the Bassac River , flows were smaller than average before 1990, but from 1990 to 1996 the opposite began to occur. In recent years, average ratios of flood flow in both tributaries were calculated. At Tan Chau, water levels of height greater than 3.5 m are characterized by an overflow of flood water into the fields, and the water levels at Tan Chau greater than 4.5 m. According to data records, the year 2000 flood did not only reach heights of 3.5 m or greater, but was also recorded as the longest duration of all floods with water levels greater than 3.5 m since 1961. However, for the category of floods which reached water levels greater than 4.5 m, the year 2000 flood did not register the longest duration. But for the year 2001 and 2002 floods, while they were not as deep as the flood in 2000, the length of time that water levels remained greater than 4.5 m was longer than that of 2000.

CHANGES IN THE OUT FLOW AND INFLOW TO MEKONG FROM CAMBODIA

Man-made (human induced) changes have had a profound effect on the flood flow discharge into Vietnamese territory of the Mekong River Delta. The construction of embankments, seepage-control constructions, and rubber dams built in Cambodia to prevent flooding of rice and vegetable crops has prevented the overflow of banks, but at the same time, has increased the flow into the canals.

Time series of the total outflow and inflow discharges to the northern part of Vietnamese Mekong River Delta show that the maximum total flow discharge to Vietnam in 1996, 2001 and 2002 were the same. However, the overbank flow discharge was the largest in 1996 and 2000; with 2002 notably the lowest. The maximum overflow in 1996 accounted for 45 % of the flow into the north-east Vietnam Mekong River Delta. The water level was more than 4 m and the flood duration was the

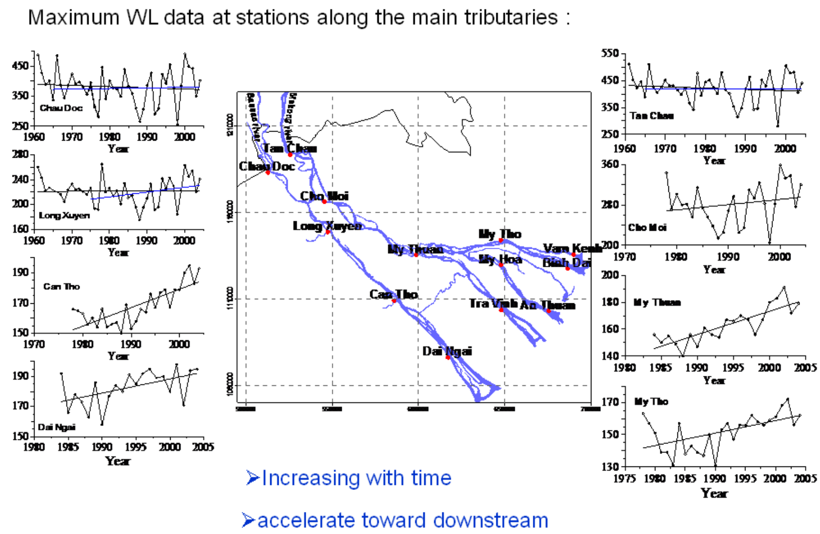

Figure 15.1: Flood peak variation trend at various stations in Mekong River

longest recorded in the last 40 years. This implies that the change in infrastructure has somehow affected the natural flood regime flow.

did flood patterns change during 1996-2000?

From 1996 to 2000, the Vietnamese government invested 3000 billion Vietnamese dong for the construction of infrastructure for mitigating flood impacts. Before the 2000 flood season, embankment systems had been developed; for example, in the Long Xuyen quadrant (LXQ) region, flood control constructions included: 1) rubber dams to prevent floods until the end of August, and which were opened after harvesting during most of the summer-Autumn crop, 2) spillway in Xuan To and the extended Vinh Te canal for draining floods into the Gulf of Thailand, 3) digging of drainage canals connecting Vinh Te canal and Rach Gia-Ha Tien canal, 4) expansion of drainage gates and dredging canals to drain floods into the Thai Gulf, and 5) sewer construction for salinity prevention.

Because of the sudden heavy rainfalls during the Monsoon season, floods are intended to propagate to the Lower Mekong River Delta. Due to the risks of climate change and sea level rise, a flood characteristic study must be conducted for the Delta. In this paper, we reported recent observations in the flood variation of the lower Mekong River delta.

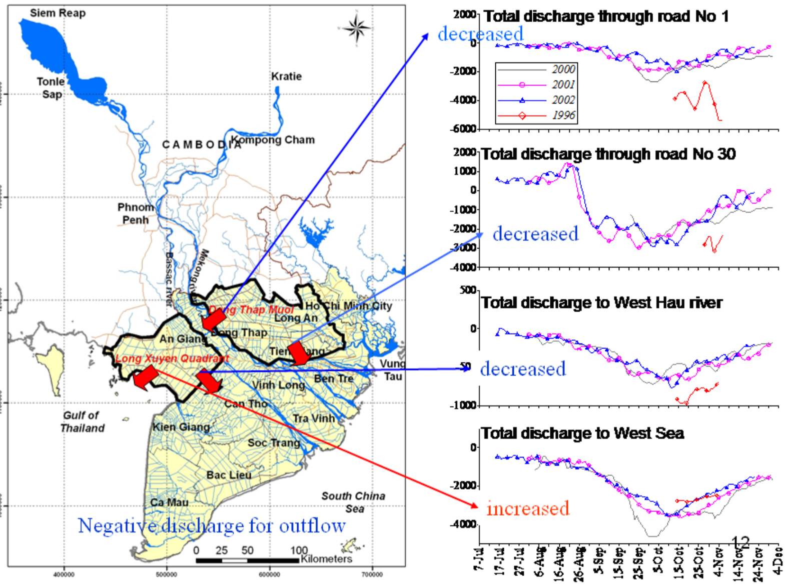

Figure 15.2: Change in outflow discharge from Dong Thap Muoland Long Xuyen quadrar

In order to assess the change of the flood regime induced by land use change and topographical change, hydro-meteorological conditions of the 2000 flood with 20-year return period is used for boundaries, with simulations carried out on the topography under 1996 using Hydro-GIS.

Differences of inundation depths between 1996 and 2000 are used to produce spatial distributions of maximum inundation depths when harvesting Summer-Autumn crop. The inundation in August decreased by 10-40 cm in LXQ, but increased 10-20 cm in upstream of DTM (Dong Tap Muoi) region. However, flood waters which drained into the Gulf of Thailand increased and caused greater inundation of the Ha Tien region. Flood water levels have increased at areas upstream of DTM limited by Dong Tien and Hoa Binh canals. In August, flood water levels downstream of DTM did not change. The profile of the maximum water level from the Bassac River to the Gulf of Thailand shows that water levels in LXQ decreased 5-30 cm at the beginning of the flood season. This implies that timely flood protected embankments and drainage canal system in LXQ affected to some extent the inundation in August.

A comparison of double rice crop areas inundated by the 2000 flood, with the maximum inundation depth in August of 1996 and 2000 was undertaken, as well as the propagation rate of flood flows into Summer-Autumn rice crops areas. The inundated area of the Summer

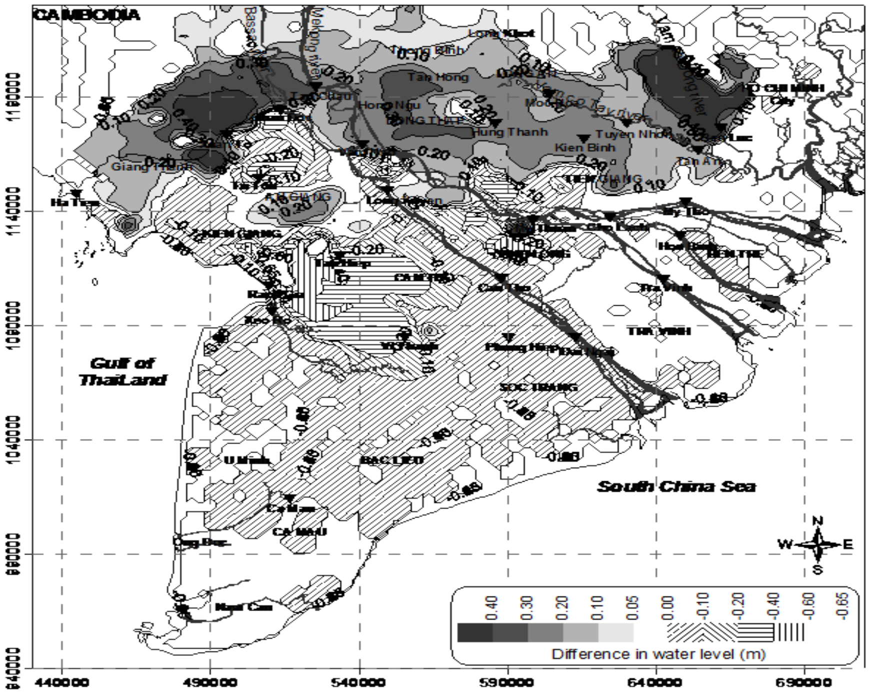

Figure 15.3: Difference of maximum water level of the year flood 2000 between 1996 and 2000

Autumn rice crop for the above two periods can be calculated for each distribution map. Differences in the inundation depths of Summer-Autumn rice crop areas between1996 and 2000 are shown in Table15.1.

Table 15.1 shows that the inundated area of Summer-Autumn rice crop decreased in the An Giang province, while it increased in the DTM and Long An, and Kien Giang provinces. This implies that flood control structures in LXQ have lowered the water level in August, but flood flow propagation to the DTM area has strengthened, causing an increase in inundation in the Long An province. Figure 15.6 shows

		Inundation depth				
Province	Double rice crop area(km2)	>0.5m	>1m	>1.5m	>2m	>2.5m
Dong Thap	1742	-115	-30	53	100	0
Long An	1906	53	5	110	34	0
An Giang	1894	-78	15	9	-77	0
Kien Giang	2162	-196	91	68	2	0

Table 15.1: Difference of inundated Summer Autumn crop area between 1996 and 2000

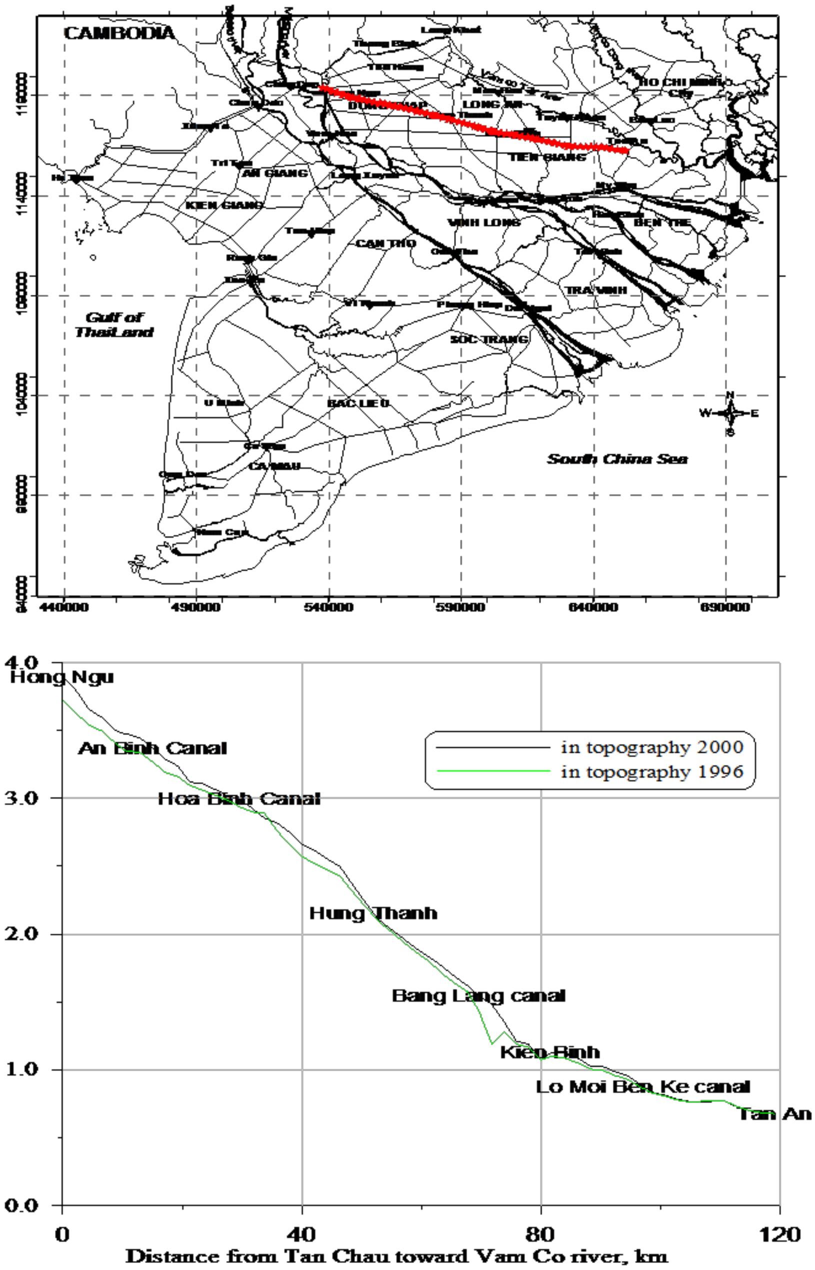

Figure 15.4: The water level profile in Dong Thap Muoi area from Tan Chau to Tan An: comparison between 1996 and 2000

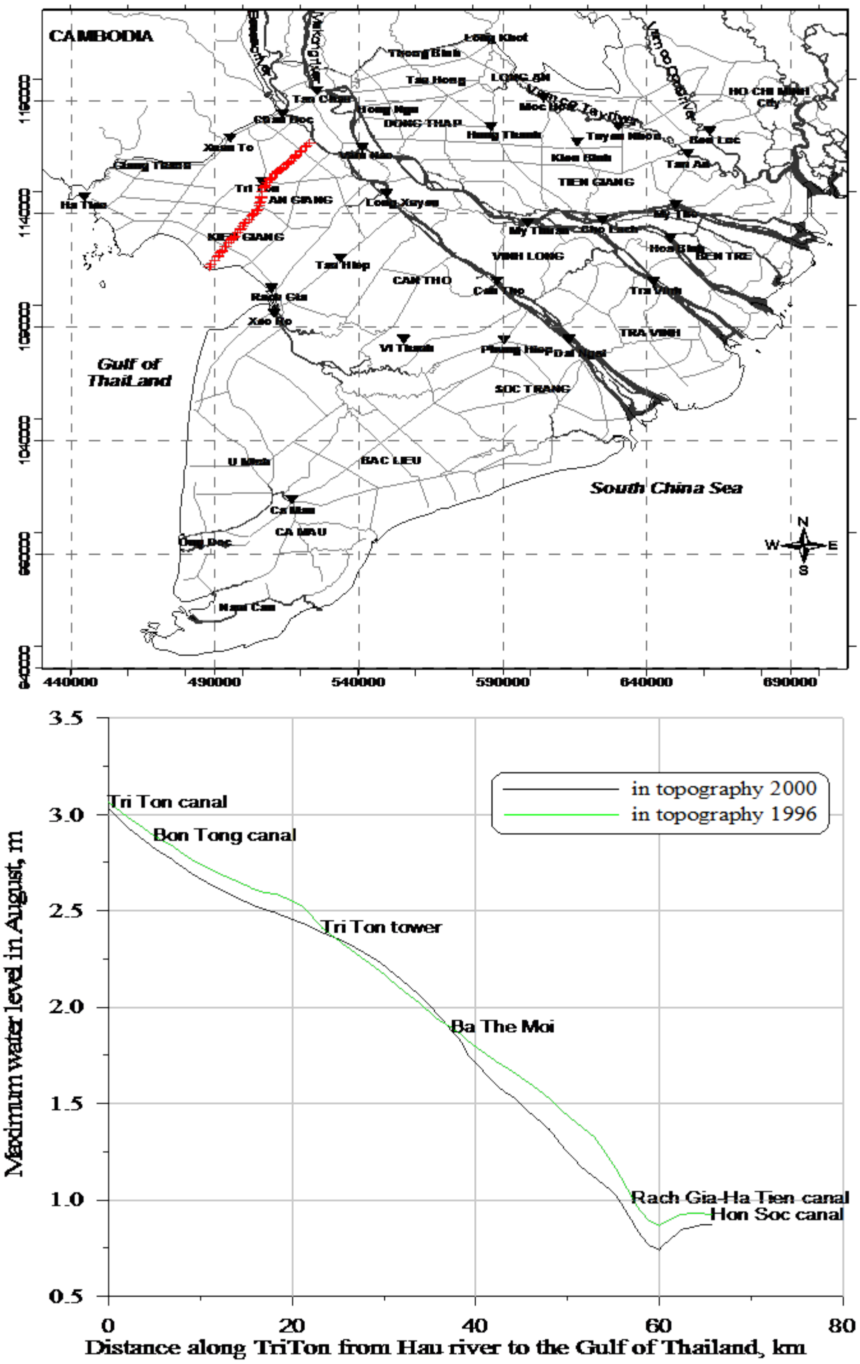

Figure 15.5: The water level profile in LXQ along Tri Ton canal: comparison between 1996 and 2000

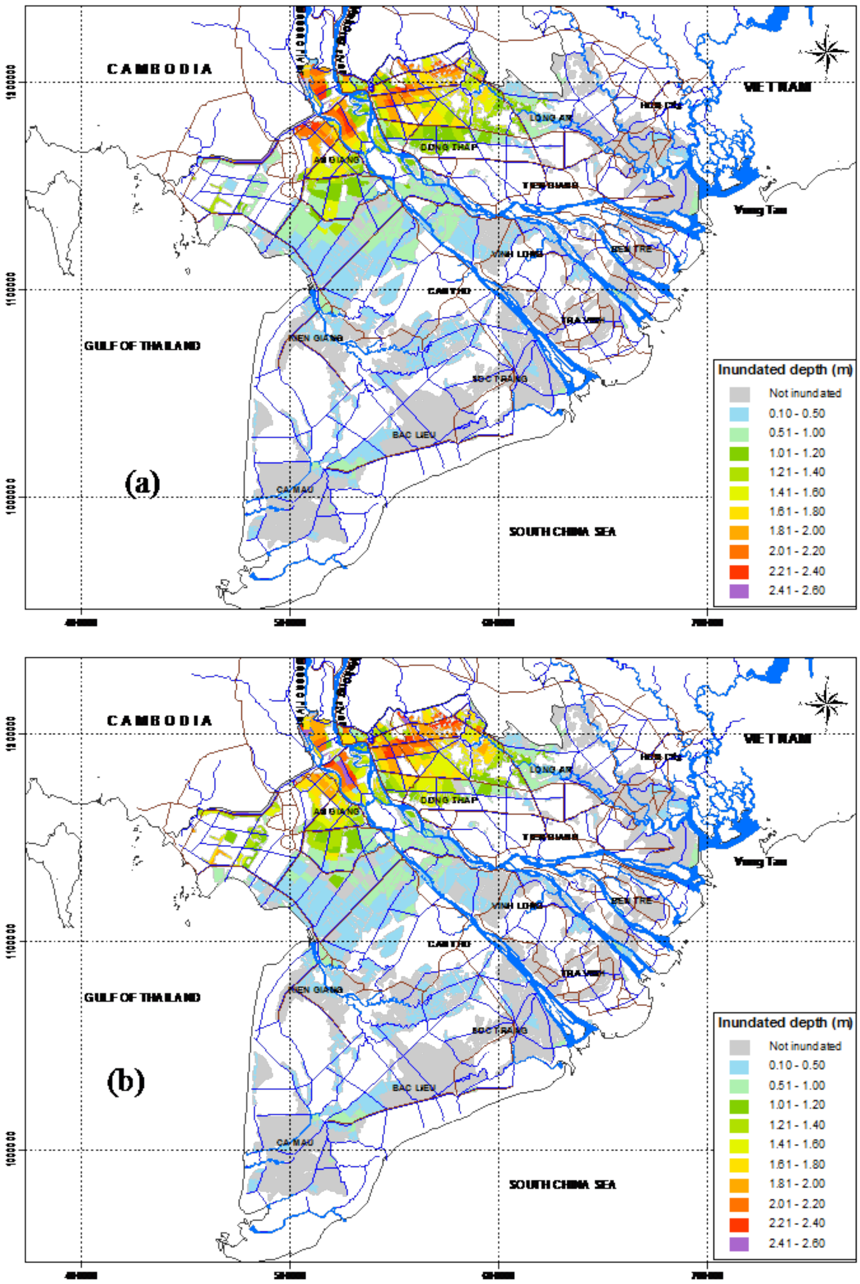

Figure 15.6: Double rice crop of land use 2000 inundated by 2000 flood in topography of 1996 and 2000

a comparison of maximum water levels during the flood season, in particular, that water level in the DTM increased by 10-30 cm.

CONCLUSION

It can be said that human induced land cover changes such as dams, sewers and canal dredging have had an effect on the hydrological regime in this region in recent years; in particular, its effects on increased water flow of rivers and canals. This is consistent with the variation trends mentioned above. Hydro-GIS model results show that recent engineering structures decreased inundation in those regions where the embankments were raised, bit which caused flood waves to propagate to other regions, causing an increase in terms of peak flood height and duration. The results show an increase in flood flow propagation into the DTM, causing higher inundation compared to the natural regime. The LXQ region was protected from early floods, but floods propagated from Cambodia to Long An and Ha Tien quadrant became faster, and synchronized with floods from the main river at Tan Chau and Chau Doc. In the DTM region, a major amount of floodwater flowed in longitudinal canals. Since the beginning of August, vast amounts of floodwater drained towards the Vam Co River, located downstream of the Mekong, causing high inundation. A major amount of floodwater flowed through the canals of Xuan To-Giang Thanh to the LXQ region. Floodwaters are then drained out towards the Gulf of Thailand; however the floods flow only through canals and gates under roads causing water-logging during peak flood periods. As such, the highest water levels reached in these areas have increased.

Considering climate change in the Mekong River Delta, the impacts induced by sea level rise should be estimated for regional mitigation planning.

16

INFLUENCE OF DEFORESTATION ON CLIMATE CHANGE: FUTURE WATER AVAILABILITY IN CHI AND MUN RIVER BASINS

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ABSTRACT

Influence of deforestation on climate change has been investigated in the Chi and Mun river basins; both are tributaries of the Mae Khong river and located in the northeast of Thailand. The drainage area of Chi and Mun river basins is about 120,537 km². Forest area in this region was found to be continuously decreasing over the last 5 decades. Temperature and annual rainfall were selected as variables to indicate the climate condition. Trend analysis of maximum, mean and minimum temperature of 5 meteoralogical stations during the last 3 decades (1978 – 2007) was conducted. The minimum temperature showed an increasing trend across all stations, while the mean and maximum temperature was found to be increasing for almost all of stations. Trend analysis was conducted on the 5 year moving average of annual rainfall from 114 rainfall stations collected over 30 years . 53% of stations exhibited an increasing trend while 43% of stations showed a decreasing trend, with the rest of the 4% showing no trend. This reveals that deforestation has only influenced an increase in temperature but not on the amount of annual rainfall due to the high interannual variation of annual rainfall in this region. Comparison between water demand and water availability in terms of the annual yield of a basin was analyzed. It was found that in terms of the annual water balance, there is still water available to meet future water demands. However further detailed studies for appropriate water management both in time scale (year-round availability) and in space scale (well distributed for all sub basins) is necessary.

INTRODUCTION

Various studies have demonstrated that land cover change provides additional forcing of the climate, through changes in the physical properties of the land surface, potentially resulting in climate change in many areas (e.g. Avissar 1995, O'Brien 2000, Betts 2001, Claussen 2002). The significant role of the land within the climate system was discussed by Wu & Newell (1998) for El Nino events. El Nino is the warming of a relatively small area in the tropical eastern and central Pacific Ocean but which has global climate consequences. Chase et al. (1996, 2000) and Clausen (2002) showed that tropical land use change had an effect on the climate system similar to that of an El Nino event. Lawton et al. (2001) demonstrated that tropical deforestation has significant regional effects on the ecological environment of adjacent mountains in Costa Rica, resulting in changes in the longitudinal distribution of thunderstorms in the tropics. However, the ability to forecast the impact of land use change on climate change is limited due to dynamic variation of atmospheric and oceanic circulation patterns and their subsequent involvement within the global climate. However, various studies concerning the impacts of land use on climate change have been conducted in almost all of regions in the world. For example, a study on the relevance of land use change on evaporation and its consequence on rainfall in Zimbabwe, Zambia and Mozambique in southern Africa was conducted by M.M de Groen and H.H.G. Savenije, (1995). Many studies have also been conducted for the U.S.A. with regards to land use change and temperature trends. Some examples include: a study on the impacts of land use and land cover change on temperature trends at U.S. climate normals stations (Hale et al., 2006), study of the influence of specific land use land cover conversions on climatological normals of near – surface temperature (Hale et al., 2008), study of the impact of urbanization and land use on climate change (Kalnay, E. and M. Cai, 2003) and study of urbanization and its detection and effect in the United States climate record (Karl et al., 1988) etc. Various studies have also been conducted in Thailand to investigate the impact of land use changes on climate change, for example, Weesakul U. and Weesakul S. (2004) studied the impact of land use change on evaporation and temperature in the northeastern region of Thailand. Weesakul (2004) studied the impact of deforestation on hydrological changes in northeastern basins in Thailand, with an emphasis on watershed management and planning. Weesakul (2005) also illustrated a case study in lower Mae Khong river basin concerning the problem of deforestation and its relevance to the basin water balance. Characteristics of rainfall variability in Chi and Mun river basins were studied by a number of researchers, for example, Phien et al. studied the distribution of monthly rainfall in northeast Thailand. Ogura et al. (2007) studied the characteristics of precipitation in Nong Saeng Village, Khon Kaen Province, northeast Thailand. In this study, the influence of land use change, in terms of deforestation, on climate change will be investigated over Chi and Mun river basins, which are located in northeast of Thailand and are tributaries of the Mae Khong river basin. Temperature and annual rainfall will be used as variables representing the climate condition. Furthermore, the amount of annual rainfall as the natural water availability over a basin will be considered, and will be compared with water demand to investigate the availability of water under climate uncertainty in this region.

Study area and data collection

The Chi and Mun river basins were selected as the study area, and are tributaries of the Mae Khong river basin. The Chi and Mun river basins are located in northeast of Thailand as shown in Figure 16.1. Total drainage area of these two river basins are 120,537 km², whose 49,477 km² belongs to the Chi river basin, while another 71,060 km² belongs to the Mun river basin. The river network consists of two main rivers namely Chi river (Mae Nam Chi) and Mun river (Mae Nam Mun), flowing from the west to the east (Figure 16.2).

The Chi river joins the Mun river at Ubonratchathani province and then discharges to Mae Khong river at Khong Jeam district. Land use maps of the area were collected from 1978 to 2002. Figure 16.2 shows land use in the year 2002, it reveals that forest area are normally located in the mountain in the upstream parts of each sub – basin. Generally most areas are used for agricultural production. Land use maps from 1978 to 2002 were analysed to assess the quantity change in forest area over these two river basins. Minimum, mean and maximum temperature were collected from 5 main meteorological stations, where 3 stations namely Khon – Kaen (381201), Chaiyaphum (403201) and Roi et (405201) are located in Chi river basin and another 2 stations namely Nakhon-ratchasrima (431201) and Surin (432201) are located in Mun river basin as shown in Figure 16.2. Temperature data was collected for 30 years from 1978 to 2007. Annual rainfall from 114 raingauges, distributed over two river basins, were also collected for the period from 1978 to 2007. Amongst these raingauges, 51 stations are located in

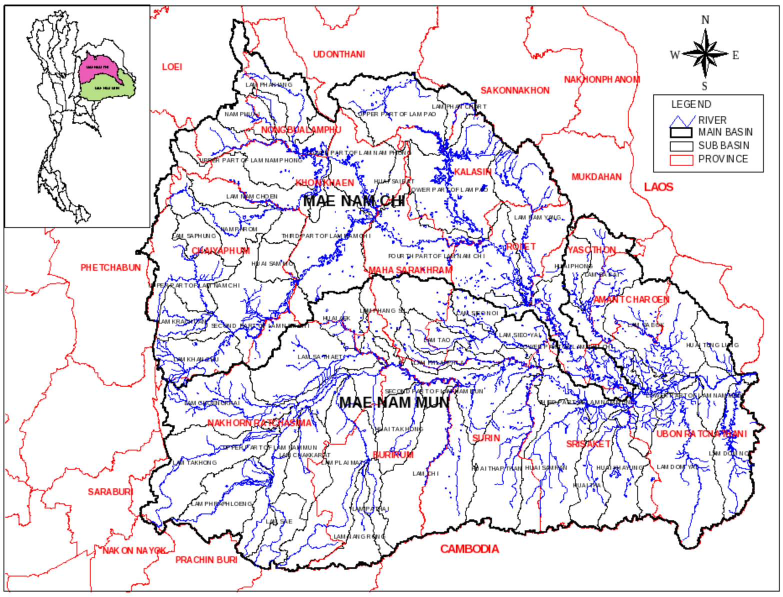

Figure 16.1: Chi and Mun River Basins

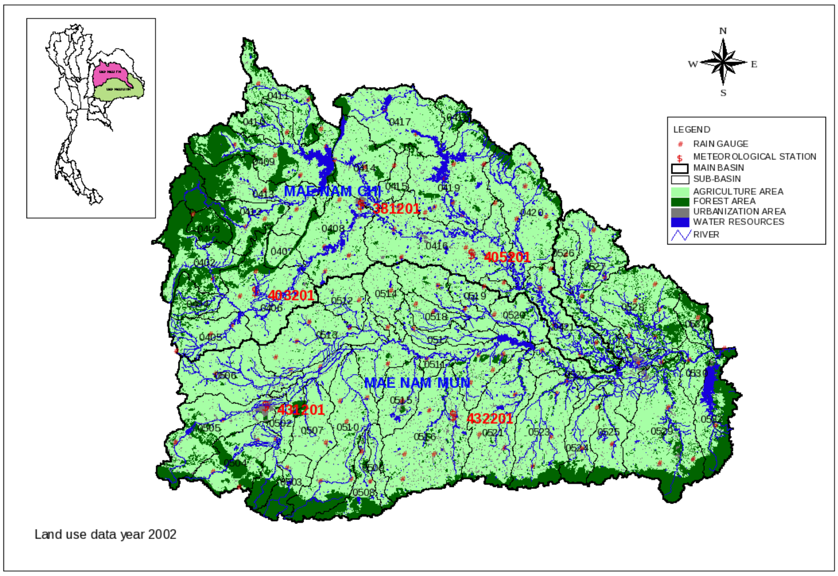

Figure 16.2: Land Use Map of Chi and Mun River Basins in Year 2002 with Location of Meteorological Stations

Chi river basin and 63 stations are located in Mun river basin as shown in Figure 16.2.

change in forest area

Analysis of change in forest area was conducted by using land use maps from 1978 to 2002. It was found that, for the Chi river basin, forest area decreased from 48% in 1978 to 20% in 1995, but then gradually increased to 25% in 2002 as a result of plantation and reforestation efforts in Thailand, during the last two decades. The results of analysis also show that in 1978 there was only 15% of forest area, which decreased to 10% in 1995. However as a result of reforestation efforts, forest area has gradually increased since 1995 to 2002, with forest area now covering about 20% over the basin, as shown in Figure 16.2.

change in temperature

Minimum, mean and maximum temperature from 5 main meteorological stations were analysed over a period of 30 years (1978 to 2007). Time series trend analysis was then conducted using this data. A 5-year moving average time series was adopted in order to minimize noise in the data. Table 16.1 summarizes the results of this trend analysis based on the maximum, mean and minimum temperature of 5 meteorological stations in Chi and Mun river basins. It reveals that for the minimum temperature, there is a distinct increasing trend in the time series. The trend for the mean, as well as maximum temperature, is increasing for 4 stations out of the 5 stations. In general, the results imply that for almost all cases, the temperature has an increasing trend in this region.

influence of deforestation on a change in temperature

Comparison between the decrease in the remaining forest area over the basin and increasing trend in temperature during the last 3 decades over Chi and Mun river basins, implies that deforestation may be one of major factors influencing global warming in this region (as shown in Figures 16.3 and 16.4). However, results of analysis in this study are only a preliminary investigation of the relationship between deforestation and climate change. The research did not study in detail, the mechanism of land use change and its resulting involvement with changes in the climate. Besides, analysis in this study is based on river basin scale,

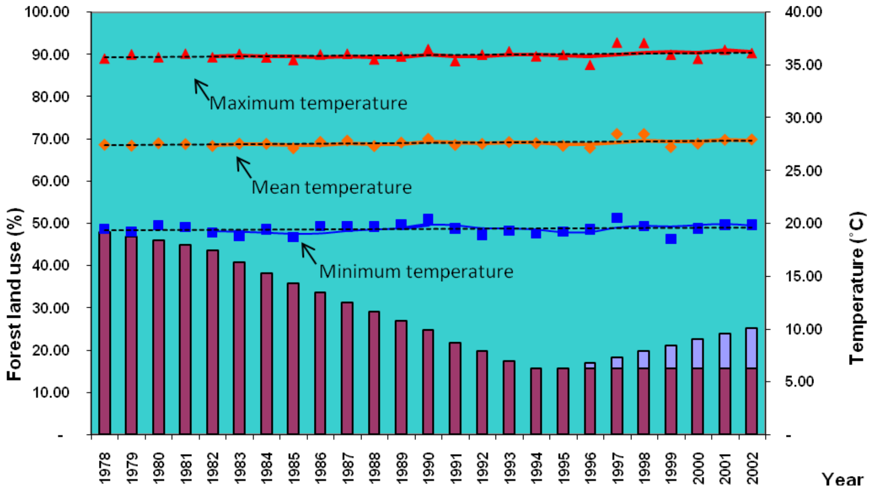

Figure 16.3: Changes in Forest Area in Chi River Basin and Change in Temperature at Khon Kaen Station

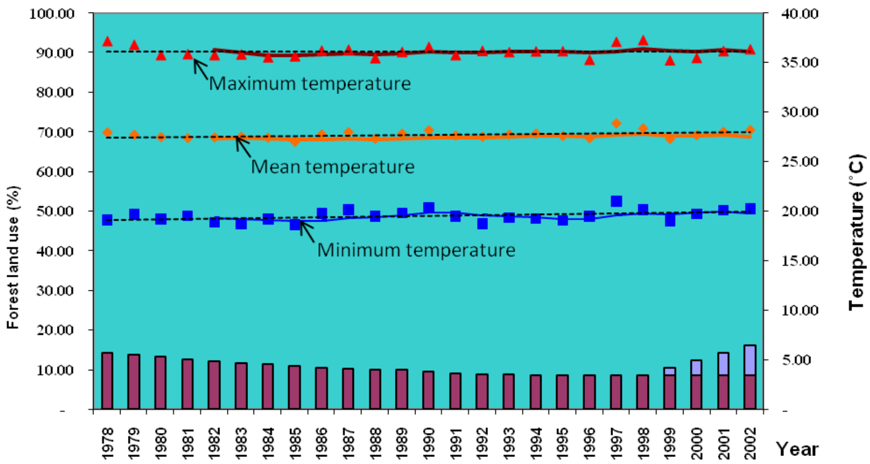

Figure 16.4: Changes in Forest Area in Mun River Basin and Change in Temperature at Nakhon-Ratchasrima Station

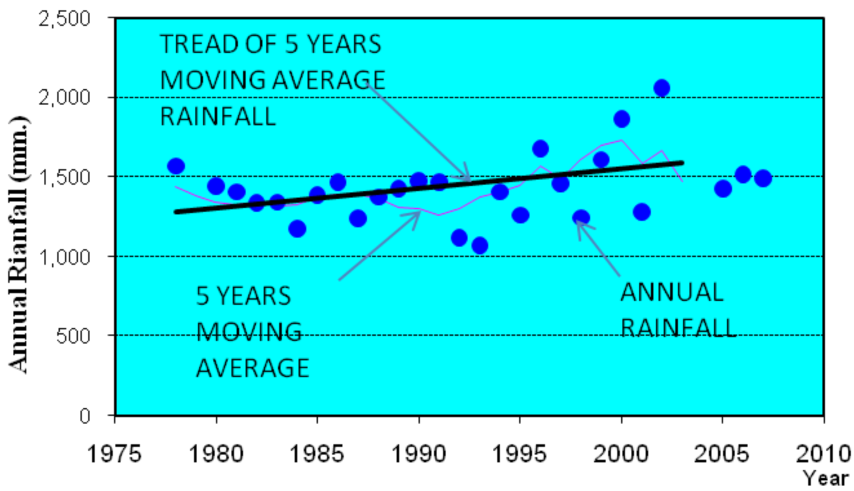

Figure 16.5: Trend Analysis of 5 years Moving Average of Annual Rainfall during 1978 to 2007 at station 62013 in Mun River basin

with limited number of meteorological stations distributed over a basin. It should also be remarked that the location of meteorological stations are not situated in the forest area and temperature measured is surface temperature. Nevertheless, despite all the limitations stated above, the results obtained from the preliminary analysis in this study illustrate that change in forest cover area provides some additional forcing on the climate, through changes in surface temperature resulting in increased temperature in this region.

impact of deforestation and increase in temperature on change in rainfall

Time series of annual rainfall over a period of 30 years of 114 raingauges, distributed over Chi and Mun river basins, were analysed. Moving average for 5 years was adopted in trend analysis to minimize noise in the data. Trend analysis of the 5 year moving average of 30 years time series of annual rainfall data was manipulated at each station, one by one. Figure 16.5 demonstrates an example of the trend analysis of the 5 year moving average of annual rainfall over a period of 30 years at station 62013 in Mun river basin. The result reveals that at this station annual rainfall tends to increase gradually.

Table 16.2 summarizes results of trend analysis of 114 raingauges in Chi and Mun river basins. The results indicate that in Chi river basin, 57% of stations had an increase in annual rainfall, while another

River Basin / Temperature	Chi River Basin			Mun River Basin	
	Station 381201	Station 403201	Station 405201	Station 43120	Station 432201
Maximum	↑	↑	↑	↑	↓
Mean	↑	↑	↑	↑	↓
Minimum	↑	↑	↑	↑	↑
Note: ↑ means increasing trend ↓ means decreasing trend					

Table 16.1: Trend Analysis of 5 year Moving Average of temperature in Chi and Mun River Basins over a Period of 30 Years

River Basin	Chi River Basin	Mun River Basin	Total
Trend	Stations (%)	Stations (%)	Stations (%)
Increasing Trend	29 (57%)	31 (49%)	60 (53%)
Decreasing Trend	21 (41%)	28 (45%)	49 (43%)
No Trend	1 (2%)	4 (6%)	5 (4%)
Total	51 (100%)	63 (100%)	114 (100%)

Table 16.2: Trend Analysis of Annual Rainfall for 114 Raingauges over a period of 30 years in Chi and Mun River Basins

41% of stations exhibited a decrease in annual rainfall decreasing. The last 2% of stations had no obvious trend. In Mun river basin, 49% of stations had an increasing trend in annual rainfall, while another 45% had a decreasing trend, with 6% having no obvious trend. Considering these results, across all stations over Chi and Mun river basins, 53% of stations demonstrate an increasing trend, 43% of stations have a decreasing trend, and 4% of stations have no clear trend. The results of this preliminary analysis implies that there is a high variation of annual rainfall both in time and space. It also reveals that neither a decrease in the forest area nor increase in temperature influences a change in the amount of annual rainfall. A high interannual variation of rainfall in this region may be due to uncertainty of the passage of depression which is one of major causes of rainfall in Thailand. However, the results of analysis in this study are based on an annual basis, which means that there may be high variation of distribution of rainfall over one year. It is interesting to conduct further detailed studies on the distribution of rainfall in the wet season and dry season in order to investigate whether wet seasons have become wetter and the dry seasons, dryer. If this is the case, watershed management is necessary to distribute sufficient water all year round.

WATER AVAILABILITY UNDER CLIMATE UNCERTAINTY FOR FUTURE WATER DEMAND

It is curious to investigate whether, under this climate uncertainty, natural water is available for future water demand or not. A number of research concerning water demand in this region, indicate that a major of water demand is for irrigation purposes, particularly for paddy cultivation, with around 10% of water for domestic and industrial use. Figure 16.6 illustrates irrigation water demand in Chi and Mun river basins during the last 3 decades, which varies year by year depending on the amount of effective rainfall; useful for rice cultivation. In this study, water availability in a river basin is defined as natural water as an average yield of a basin. Rainfall and runoff relationships, in these two river basins were studied by a number of researchers, a value of 0.3 is taken as an average ratio between annual runoff and rainfall, (Weesakul and Pahonepipat, 2000) and was adopted in this study. Therefore water availability, is defined in this study as 0.3 multiplied by annual rainfall and is considered as natural water availability in the river basin (Figure 16.6). Comparisons between water availability under uncertainty in annual rainfall and water demand in Chi and Mun river basins (Figure

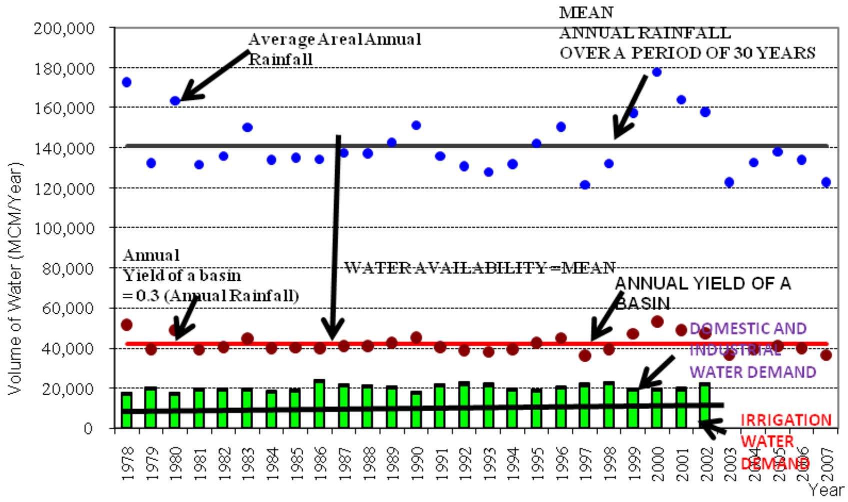

Figure 16.6: Comparisons between Water Availability and Water Demand in Chi and Mun River Basins

16.6) reveals that there is still water available in terms of the annual water budget. However, it is necessary to further study into detail, both in time and space, whether this amount of water is well distributed both in wet and dry seasons, and whether the water is well spatially distributed for all sub-basins.

CONCLUSION

Land use maps of Chi and Mun river basins were analysed in the study to quantify amount of forest area remaining over a basin. Temperature and annual rainfall were selected as variables indicating climate condition in the region. Trend analysis of maximum, mean and minimum temperature of 5 meteorological stations over the last 3 decades was conducted. Trend analysis of annual rainfall of 114 raingauges was manipulated. It has been found that deforestation may be one of the major factors influencing global warming in this region. However, neither deforestation nor global warming has influenced changes in the amount of annual rainfall. Comparison between water demand and water availability in terms of annual yield of a basin was analysed. It shows that high interannual water demand depends on amount of effective rainfall for rice cultivation. It also reveals that for the annual water budget, there is still water available to satisfy future water demands. However, further detailed studies (both in time and space) on appropriate water management strategies are necessary.

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Part III

FOOD SECURITY

17

IMPACTS OF CLIMATE CHANGE AND SEA LEVEL RISE ON THE INTEGRATED AGRICULTURE-AQUACULTURE SYSTEM IN THE MEKONG RIVER BASIN : A CASE STUDY IN THE LOWER MEKONG RIVER DELTA IN VIETNAM

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EXTENDED ABSTRACT

The Mekong River is the 7th-longest river in Asia. Its estimated length is 4,350 km, flowing through six countries: China, Burma, Thailand, Laos, Cambodia and Vietnam before its water flows to both the South China Sea. The Mekong River Basin is considered as one of the basins that will be strongly affected by climate change and sea level rise. Climate change in Southeast Asia will create a crisis of water resources basin-wide, negatively impacting the food security, affecting the livelihoods of many vulnerable groups, threatening the ecology of wetlands, depleting biodiversity and creating other fluctuations in socio-economic sectors.

The livelihood condition in the Mekong river delta is sensitive and could be threatened by changing climate and hydrological cycles. Future climate projections from regional climate models indicate that the Mekong River Delta region tends to be warmer in the future with longer and drier summertimes. Seasonal patterns could be altered under global warming. As a consequence, the salinity intrusion situation in the Mekong River Delta will become more serious. Moreover, changing the climate pattern in the upstream region of the Mekong River also affect the flow regime of the Mekong Delta in the rainy season, where the boundary of future floods could expand to a wider coverage. Warmer temperatures and changing precipitation patterns will likely reduce agricultural productivity. Rice farmers, shrimp farmers, salt farmers and small agricultural businessmen will be significantly impacted due to the lack of essential nutrient sources, land ownership, financial sources and information for assessing climate and flood regime change. Resources areas of forest, land, water, wildlife, natural minerals will become encroached, over exploited and damaged.

This paper presents the potential impacts of climate change and the key concerns on future climate threats, especially to the rice and fish production sector of the Mekong River Basin in general and the Lower Mekong River Basin in particular. Finally, copping and adaptation studies are proposed and discussed.

Key words: the Mekong River Delta; Climate change; Sea level rise, Integrated Agriculture-aquaculture system, Impacts.

BACKGROUND

The Mekong River rises from the Qinhhai-Tibetan plateau of China and flows through six countries in Asia: China's Yunnan province, Burma, Thailand, Laos, Cambodia and Vietnam before entering to the South China Sea (figure 17.1). The Mekong river collects and supplies water for a large basin of nearly 800,000 km². The Mekong River plays an important position in the supply of water resources for food production, energy generation and ecological sources. The Mekong River Basin is considered as an extraordinary and unique biodiversity comparable to that of the Amazon Basin (WWF, 2004). Frequently overflowing flood waters create the rich wetlands and the biodiverse ecosystems on either side of the Mekong river banks, especially in Cambodia and Vietnam (Tuan et. al, 2007).

The Mekong Basin is a living place for more than 60 million people settled mainly along the main river and its tributaries. It is estimated that seventy-five percent of the population in the Lower Mekong Basin are rice farmers and fish/shrimp farmers. The farmers in the whole basin provide enough rice and staple diet to feed more than 300 million people a year (Mekong News, 2003). It is estimated that each year, the Mekong people can harvest up to 2.6 million tons of wild fish and other aquatic resources (MRC, 2009) as the world's largest inland fishery. This is the reason why rice and fish are the major foods in Mekong region both for the rural and remote areas and for the residents of towns and cities. Significantly, the whole basin is one of the biggest in the production of both rice and fish not only providing for domestic consumption, but also as an export to the rest of the world. The Mekong River Delta in Vietnam, the most downstream part of the Mekong River Basin, is really the largest agriculture and aquaculture production region of the Vietnam. Agriculture and aquaculture sectors are always the priority focus of rural development policies of the Governments of Thailand, Lao, Cambodia and Vietnam in the last 30 years.

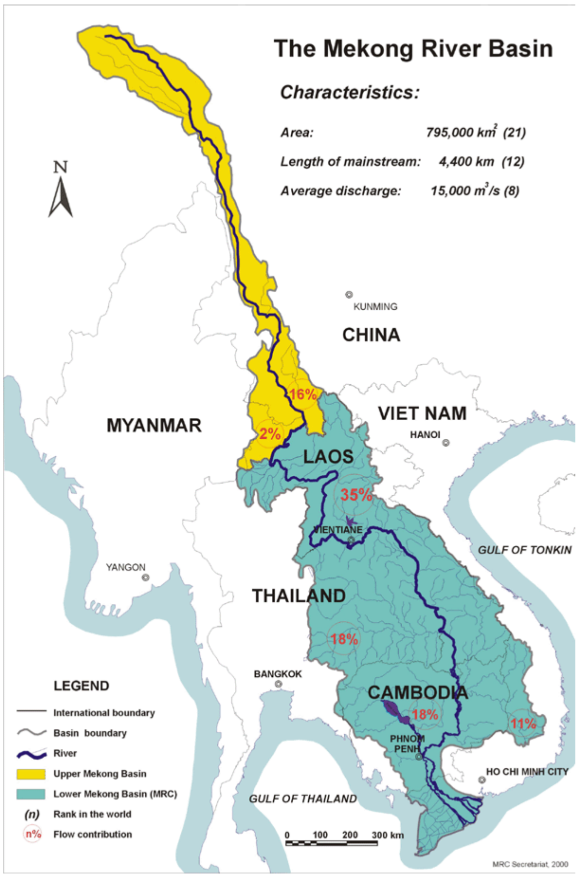

Figure 17.1: Mekong River Basin map and water distribution in each country involved (Source: MRC, 2000)

The natural characteristics of hydrology, climate, soil and topography combined with the active population of the Mekong River Basin make the Lower Delta area in Cambodia and Vietnam the most suitable for rice cultivation and for fishery and aquaculture all year round. Almost all people of the basin have settled and cultured densely along the river and canal banks. Human life, agriculture and aquaculture production, domestic water supplies in the region depends highly on the meteorological and hydrological regime. Around the Tonlesap River (the Great Lake) area is extremely rich with fish habitats and other aquatic resources, especially in the annual flood seasons. Both the inland and coastal water of Cambodia contribute an estimated 360,000 ton of fishes, adding about 8.4 percent to GDP. A Cambodian can consume about 40-60 kg fish per year as the most important source of animal protein.

Since the end of the decade of 1980s up to present, Vietnam is known as one of the biggest agriculture and aquaculture export countries. In average, about 3 – 3.5 million tons of rice and 600,000 - 700,000 tons of fish are exported yearly from Vietnam to the rest of the world. In 1999, 4.5 million tons of exported rice has been recorded. Vietnam is now the second largest exporter of rice in the world market after Thailand. It is projected that, the total aquaculture production in the MD can reach the target of 1.5 million tons in 2010 and 2 million tons in 2020. This increase in fish production and processing will also generate more jobs for local workers, with the number of workers involved in this sector estimated to increase from 200,000 in 2010 to 250,000 in 2020 (Vietnam News Agency, 2008).

In the many rural areas of the MD, the common integrated agriculture -aquaculture system (IAAS) is a part of the integrated garden-livestock-fish/shrimp-rice system. This system seems an efficient farming system that supplies both rice and fish/shrimp for farmers. IAAS spread throughout Vietnam during the past 20 years notwithstanding the global trend of specialization in agriculture (Nhan, et.al., 2006). Recently the IAAS has intensified in response to increasing market demands and the need to improve livelihoods (Bosma et al., 2006; Phong et al., 2008). Other rice-farming countries in Asia, are also applying integrated rice-fish farming widely including Thailand, Cambodia, and Vietnam. Practically, IAAS is a low-cost, low-risk option for poor rice farmers. The rice–fish-farming system is also of great significance for global food security and global change (Jianbo and Xia, 2006). Over the last 2 decades, the number of rice-fish farmers has increased rapidly

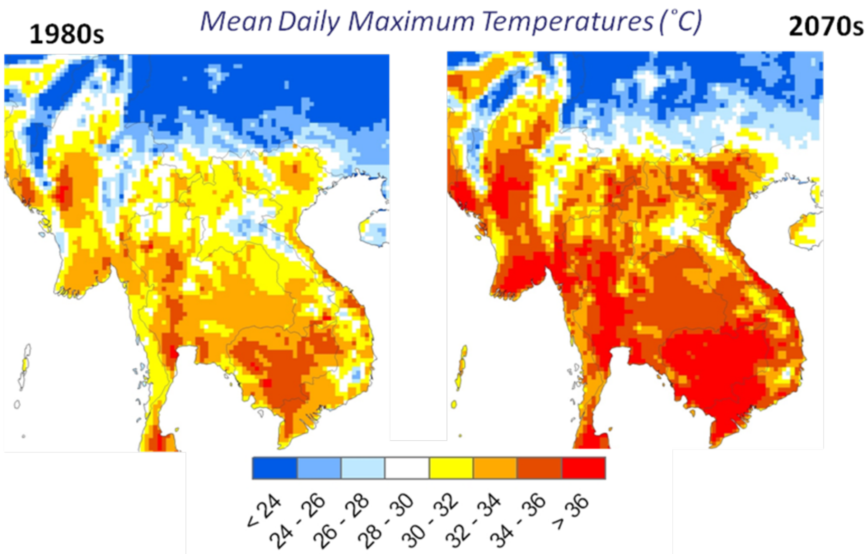

Figure 17.2: The projected change of mean daily maximum temperature in the Mekong Region since 1980s to 2070s (Source: TTK & SEA START RC, 2009)

due to the agriculture and aquaculture promotion programs by local governments, scientists and NGOs.

CLIMATE CHANGE PROJECTIONS FOR THE MEKONG REGION

For more than ten years, climate change has become one of the most pressing socio-economic and environmental issue for the world. The change in global climate will threaten crop failures, damage life and cause other critical ecosystem vulnerabilities, especially in Asia and Pacific Ocean region. The Mekong River Delta is a "hot spot" for climate change, which is one of the three most vulnerable deltas in the world. IPPC (2007) has warned that if the sea level rises by 1 meter, the Mekong Delta may lose 15,000 – 20,000 km^2 of land, and about 3.5 to 5.0 million of people will be affected. However, the above estimated data is simply based on the consideration of the Delta's natural topography and current population distribution only. Other factors like rainfall, upstream floods, storm surges, sea tide, etc. have not been calculated yet.

Based on the results from the Global Circulation Models (GCMs) combined with the downscaling regional climate model PRECIS (developed by the Hadley Center for Climate Prediction and Research), it is projected that in the coming next 2 - 3 decades in the Mekong Basin the average max/min temperature will increase from 1 – 3 °C in

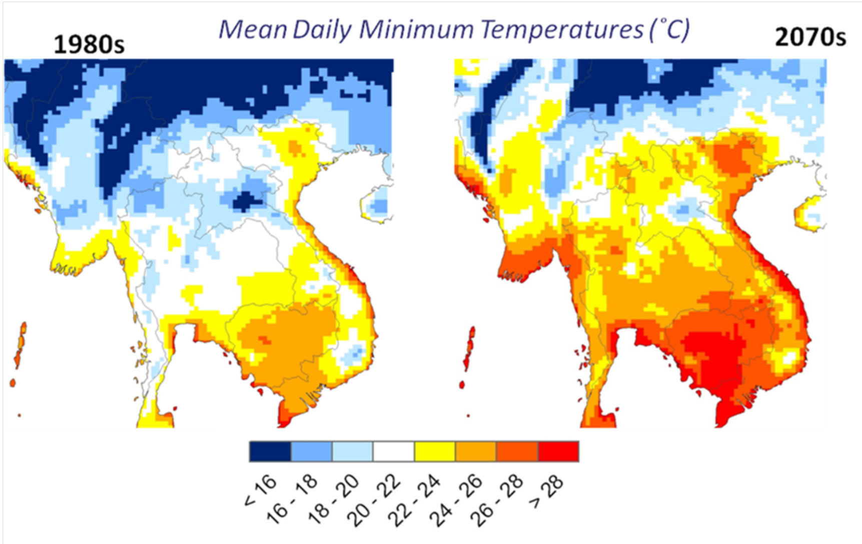

Figure 17.3: The projected change of mean daily minimum temperature in the Mekong Region since 1980s to 2070s (Source: TTK & SEA START RC, 2009)

the hot months (from January to April) (figure 17.2 and figure 17.3). The dry seasons are predicted to lengthen and intensify and the wet seasons are expected to shorten due to its late start(of up to 2 weeks). The decease in water flow from the upstream of the Mekong River in the dry seasons plus the sea level rise phenomena may lead to more serious saline intrusion into the Lower Mekong River Delta in Vietnam. Salinity intrusion in the Mekong Delta region is expected to increase, resulting in changes to cropping patterns and productivity and negative effects on aquatic and terrestrial ecosystems (MRC, 2009). Rainfall will be lower in the early part of the rainy seasons (April – May) but it may increase dramatically at the end of the rainy seasons (September – October). Under the projected climate in 2030, the north-east Thailand region and the Tonle Sap catchment of Cambodia will to suffer high water stress during the dry season (Eastham et. al., 2008).

According to Supparkorn (2008), if CO2 concentration in the atmosphere doubles from today, the rainfall in the whole Mekong Region will be changed as in figure 17.4. It is also projected that the duration of the flood days in the border area of Cambodia – Vietnam, in Long Xuyen Quadrant and the Plain of Reeds may be reduced. Otherwise, the flooded area may extend its inundation boundary towards Ca Mau Peninsula. The storms seem to move down to the southern region in the South China Sea. A combination of higher temperatures, lower rainfall, more extensive flooding and a rise in sea level will impact significantly on agricultural activities and on rice production in particular, adding more pressure to the livelihoods of people in the delta area (TTK & SEA START RC, 2009).

IMPACTS OF CLIMATE CHANGE AND SEA LEVEL RISE ON IAAS AREAS IN THE MEKONG DELTA

The climate change and sea level rise in the Mekong Region will threaten the sustainable development of agriculture and aquaculture production, including the IAAS. IAAS is considered as an efficient and environmentally sound farming practice to increase the income for farmers at low costs. In IAAS, fish is raised mainly in water bodies around rice fields to consume agricultural by-products and wastes. Practically, water in IAAS is unbalanced between rice and fish. Hence, any unfavorable change of water and weather may lead to a fall in the total harvest. In productivity chains of IAAS, the failure in each growing stage will affect the others. The potential change in monthly rainfall distribution such as less rains in early wet seasons and more heavy rains in the end of the wet seasons will reduce rice production. Rice yields decline 10% with 1°C increase in minimum temperature (Peng et al., 2004). Almost all fish and shrimp species develop favorably in optimum water temperatures in the range of 20° to 25°C. Aquaculture yields may decline precipitously at water temperatures above 30°C especially as dry lands expands.

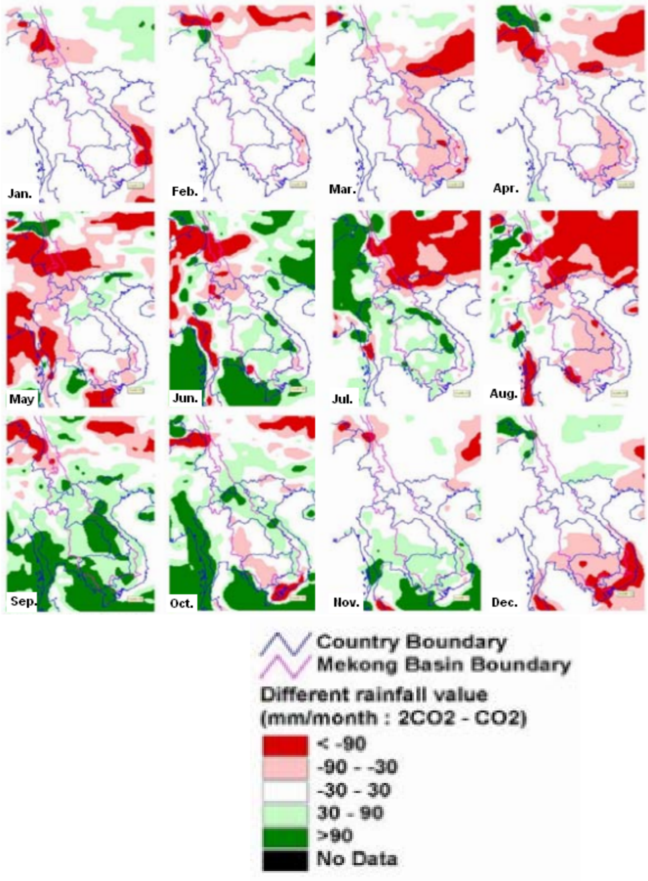

Figure 17.4: Difference in the rainfall: comparison rainfall level in the region at 1xCO2 at present time and 2xCO2 levels in the future. (Source: Supparkorn, 2008)

High air warming is a favorite condition for insect species development. A higher prevalence of infectious diseases is also forecasted for the area(MRC, 2009). Increased insect species will threat agriculture yields and farmers income. Temperature increase plus the natural flow decrease may lead to the dissolved oxygen concentration in water bodies. Water-borne diseases will be extended and attack rice-fish farmers. Low flow, high temperature and less oxygen in water bodies will affect the fish reproduction and growth. Great variations in the flow of the Mekong River, from seasonal flooding and low water levels, both drives and constrains the productivity of the agro-and-aqua-ecological systems critical to alternating seasons of rice cultivation and fishing in wetlands and floodplains (IDRC, 2008). Sea level rise and saltwater intrusion will cause major impacts especially in the MD's coastal areas. The change of salinity in coastal areas may drive changes in fish species distribution. The processes of fish migration in the Mekong River may be interrupted by the negative variation of river flow in quantity, quality and duration. More storms and sea surges may attack shrimp ponds and other fishery infrastructure (such as coastal dyke erosion and blow-off) in Vietnam coastal areas. Coastal and estuarine mangrove forest wetlands and other submerged aquatic vegetation as habit and nutrient sources for fish species will be affected by sea level rise. All negative impacts will affect the sensitive relationships of IAAS.

Furthermore, the appearance of extreme events in meteorological and hydrological phenomena such as heat waves and stresses, dry spells, unregulated rainfalls, decreased water availability, more frequent droughts, floods, cyclones, etc. may lead to many negative effects on the local socio-economic development of the Mekong Basin. Such potential climate change will also negatively affect water and food security. Kirby and Mainuddin (2009) has stated that the anticipated changes to climate and flow are expected to affect agriculture and food production, making it more difficult to meet the increased food demands from a growing population. Rice farmers, fish/shrimp farmers, salt farmers and small agricultural businessmen will be significantly impacted due to the lack of essential nutrient sources, land ownership, financial sources and information assessment for adaptation to climate and flood regime change. Then, resource areas of forest, land, water, wildlife, natural minerals etc. will be encroached, over exploited and damaged. Not only is the agricultural sector highly vulnerable to climate change, it is also one of the sectors most distorted and heavily influenced by a wide range of local, regional, national and international trade policies (Keane et al., 2009).

For short and long term development, Mekong River Basin countries should build their own climate change adaptation strategies at the community, regional and national levels. Among the mitigation and adaptation measures, hydropower plants and irrigation dams in main and tributary streams seem an alternative development priority the Upper River countries for serving renewable energy and regulating water demands highly. These upstream reservoirs will reduce vulnerable variation of water flows between wet and dry seasons due to storage of huge amounts of water in the wet season and release of stored water in the dry season. However, the operations of the dam-reservoir-

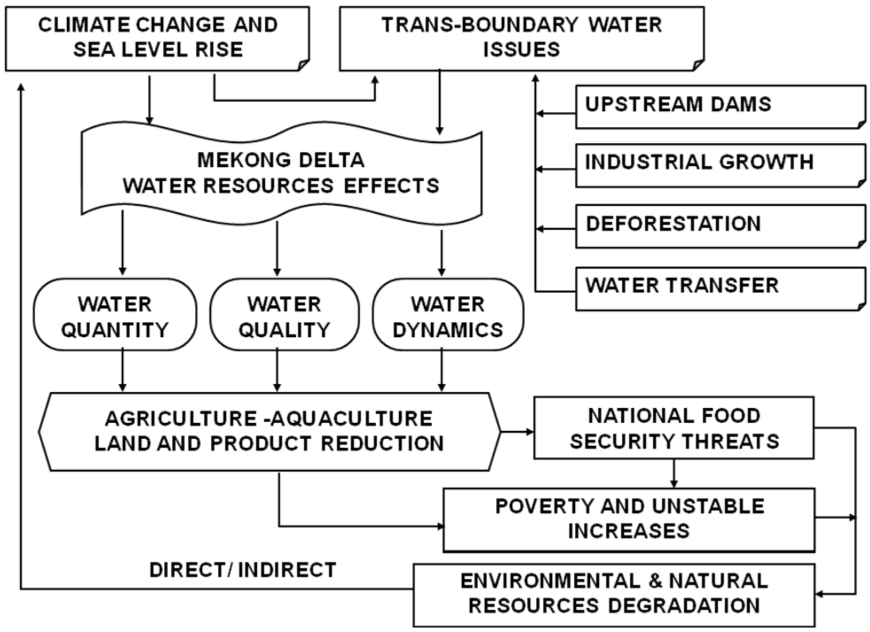

Figure 17.5: Impacts of the combined climate change and trans-boundary issues to the Mekong River Delta's water and food

hydropower systems may alter environmental flows and ecosystems downstream. So, the Lower Mekong River Regions may have double impacts – climate change and upstream development - as a consequence. The trans-boundary issues combined with climate change impacts can lead to a problem chain as illustrated in figure 17.5.

DISCUSSION AND RECOMMENDATION

The poor people of the MD depend highly on inland waters. They may access water from the streams as an important part for integration within farming systems. In Lower Mekong River region, the impacts of climate change have already been exposed, such as increasing high temperatures, more serious droughts, water stress, irregular high tides and deeper salinity intrusion. In combination, projected climate, industrial development, and upstream development could pose new challenges to local rice and fish cultivation in the Lower Delta. Adaptation to these challenges are needed.

Climate change impacts on integrated agriculture and aquaculture are uncertain because the results of different models for several rice and fish crop-yields vary widely. It is recommended that adaptation research for a sustainable IAAS under the climate change scenarios must be continued in order to secure food production in both Cambodia and Vietnam.

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18

IMPACT OF CLIMATE CHANGE ON RAINFED RICE YIELD IN NORTHEAST THAILAND

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ABSTRACT

A simulation study was undertaken to investigate the effects of climate change on rainfed rice yield using the CERES-Rice crop growth model. The crop physiological data from the field experiments conducted in Ubon Ratchathani, Khon Kaen and RoiEt provinces in Northeast region of Thailand was used to calibrate the model. Future climate scenarios for the period 2020-29, 2050-59 and 2080-89 were developed using the global climate model, ECHAM4 and downscaled using the regional climate model, PRECIS. Results indicated that there will be a reduction in the rice yield by about 18, 28 and 24% in the region during 2020s, 2050s and 2080s, respectively, compared to the average yield of years 1997-2006. There is a need to identify suitable agro-adaptation and policy measures to address the threats induced by climate change on rice production in the region.

keywords: Climate change, Global warming, Forecasting, CERES-Rice, Northeast Thailand.

INTRODUCTION

Global warming and associated climate change will affect agricultural crop yield because of alterations in temperature and rainfall cycle and through changes in soil quality, pests and diseases. The yield of food crops (rice, wheat, maize) is expected to decline with changing climate. The decline in yield is mainly due to shortening of growth period, decrease in photosynthesis ability and increase in respiration, demanding more water availability. The effect of climate change is a major concern to rice production in Asia, which accounts for more than 80% of world production and consumption (FAO, 2004). Due to limited irrigation development, a significant portion of this production is contributed by rainfed areas in Asia.

According to the study of IRRI crop modeler, John Sheely, for every 75 ppm increase in CO_2 concentration, rice yield will increase by 0.5 t/ha and for every 1°C increase in temperature rice yield decreases by 0.6 t/ha. This was the general rule determined by Free-Air CO_2 Enrichment (FACE) experiments (Wassmann, 2007). Ziska et al. (1997) derived that increase in CO_2 concentration (ambient +200 ppm and ambient +300 ppm) increases the total plant biomass by 31 and 40% and grain yield by 15 and 27%, respectively. Increase in temperature by 4°C along with above increase in CO_2 does not alter the biomass yield but reduces the grain yield and quality.

Several modeling studies revealed that increase in CO_2 and temperature will alter the rice production significantly in Japan (Horie, 2005), China (Erda et al., 2005), Thailand (Buddhaborn et al., 2004), Lao PDR (Inthavong et al., 2004), and India (Krishnan et al., 2007). Saseendran et al. (1998) found that the CERES-Rice crop growth model can predict the grain yield within an error of 3% for the agroclimatic conditions of the state of Kerala in India. Similarly, FengMei et al. (2005) evaluated CERES-Rice using data from 129 experiments conducted during 1981-2000 at different locations in China and found that the simulation results are in agreement with the observed rice yields. However, studies on impacts of future climate change on rice yield in most of the Southeast Asian countries are very limited, especially under rainfed conditions, where, even a less reliable, but earlier forecast may be more valuable than an accurate but late forecast (Sivakumar, 2006). Thus, there is a need to predict the future climate regimes, the way it affects the CO_2 concentration, temperature, water cycle etc. and the rice yield under the changed scenarios. The objective of the present study is to assess the impacts of future climate change on rice yield in Northeast of Thailand using CERES-Rice model (DSSAT version 4.0).

Study area

The Northeast is the poorest region in Thailand with majority of population engaged in agricultural activities. The region has a tropical climate with average temperature ranging from 19.6 to 30.2°C. October to February is cool season while March to May is hot season with highest temperature in the month of April. Rainfall in the region is highly unpredictable, mainly concentrated in the rainy season i.e. from May to October. The variation in the annual rainfall is from 2000 mm

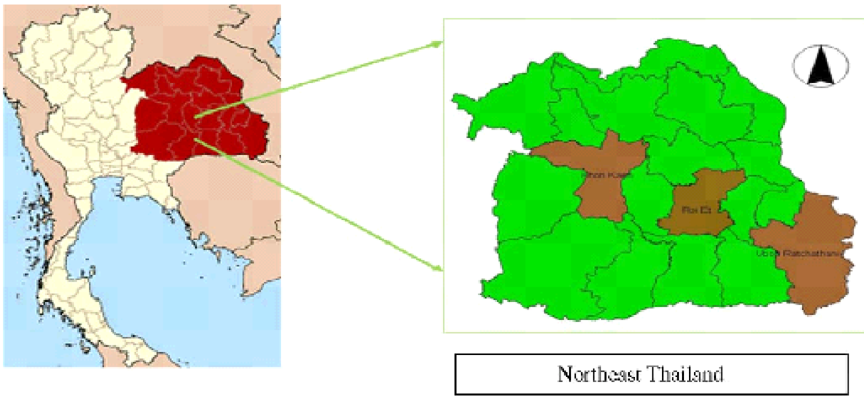

Figure 18.1: Location map of study area

to 1270mm. The region is drained by Chi-Mun River system which joins the Mekong River. Soils of the region are highly acidic, saline and infertile.

The region has about 9.3 million ha of agricultural land, of which about 7.9 million ha is under rainfed farming. Up to 75% of this land is devoted to rice, and the planted area varies considerably from year to year. The present study uses climatic and soils data and other information from crop experiments conducted at the Rice Research Centers (RRC) in three provinces, Ubon Ratchathani, Khon Kaen and RoiEt, (figure 18.1). Rice is the main crop which is sown in June to July and harvested in November to December. About 70% of the paddy rice sown is transplanted and the remaining area is sown by broadcasting and pre-germinated seeds.

As a result of the poor physical endowment of the region, generally poor soils, highly uneven distribution of rainfall and very limited irrigation facilities, average rice yield in the region area is 1.9 t/ha, which is the lowest in the country with the country average of 2.5 t/ha (Haefele et al., 2006). Rainfed rice is grown under poor conditions, i.e. poor crop management with low inputs and is subjected to climatic variability. The major production constraints are high rainfall variability, drought, submergence and inherent low soil fertility (Kupkanchanakul, 2000). The main varieties of Jasmine rice, KDML105 (Khao Dok Mali 105) and RD6 are medium-maturing varieties and cover almost 80% of rice fields in Northeast Thailand (Miyagawa, 2001).

METHODS

Crop simulation model

Windows based CERES-Rice model (DSSAT version 4.0) released in 2004 by International Consortium for Agricultural Systems Application, University of Hawaii, USA was used in this study. The model is based on understanding of plants, soil, weather and management interaction to predict growth and yield. Yield limiting factors like water and nutrient stresses (N and P) are considered by the model. A suite of tools including XBuild to create and modify experiment files, Weatherman for weather data, GBuild for graphing of outputs, ATCreate for observed data and SBuild for soil database are available for data management and analysis. It is process-based, management-oriented that can simulate the growth and development of rice as affected by varying levels of water and nitrogen. The model can identify gaps between potential and on-station and on-farm yields. In CERES-Rice genetic coefficients for different cultivars are used as model inputs to describe crop phonology in response to temperature and photoperiod. Rice yield is simulated using soil and daily weather data (Timsina et al., 2004). The input parameters for CERES-Rice model are:

- Daily weather data: max. and min. temperature, relative humidity, rainfall, solar radiations.
- Crop data: experimental data on time series crop biomass, leaf area index at various crop growth stages and grain yield.
- Soil data: Physical properties: soil texture and structure, water holding capacity and bulk density. Chemical properties: nitrogen content, phosphorous content, potassium content, total volatile solids, carbon and ash content.

The genetic coefficients used for growth and developments of rice varieties are: P1, Basic vegetative phase, it is the time period expressed as growing degree days (GDD) in °C above a base temperature of 9°C; P2O, Critical photoperiod or the longest day length in hours at which the development occurs at a maximum rate; P2R, Photoperiod sensitivity coefficient, extent to which the phasic development leading to panicle initiation is delayed; P5, Time period in GDD °C from beginning of grain filling to physiological maturity with a base temperature of 9°C; G1, Potential spikelet number per panicle; G2, Single grain weight; G3, Tillering coefficients relative to IR64 cultivars and G4, Temperature

Rice Cultivar	Genetic Coefficient							
	P1	P5	P2R	P2O	G1	G2	G3	G4
KDML105	502.3	386.5	1233.0	12.7	45.7	0.027	1	0.95

Table 18.1: Genetic coefficients of rice cultivars, KDML105

tolerance coefficient. The genetic coefficients for the rice cultivars used in this study are as given in table 18.1.

The various processes simulated by the model are phenological development of the crop; growth of leaves, stems and roots; biomass accumulation and partitioning among leaves, stem, panicle, grains and roots; soil water balance and water use by the crop; and soil nitrogen transformations and uptake by the crop. The phenological stages simulated by the model are sowing or transplanting, germination, emergence, juvenile phase, panicle initiation, heading, beginning of grain filling, end of grain filling, and physiological maturity. The model simulates the total biomass of the crop as the product of the growth duration and the average growth rate. The simulation of yields at the process level involved the prediction of these two important processes. The yield of the crop would be the fraction of total biomass partitioned to grain. The data obtained from the field experiments conducted by the Rice Research Centers at Ubon Ratchathani, Khon Kaen and RoiEt for crop growth characteristics, i.e. flowering day, maturity day, grain yield and harvest index was compared with the simulated results for model calibration. The observed and simulated weather data for 1980-89 was used as input in the calibrated model and the yield outputs at the three locations were used for model verification.

Climate model

The future climate scenarios used for this study were collected from the Southeast Asia START Regional Center at Chulalongkorn University, Thailand. The future climate data was predicted using the Global Climate Model ECHAM4 (ECMWF Atmospheric General Circulation Model coupled with University of Hamburg Ocean Circulation Model) developed for the global resolution of 280x280 km by Max Plank Institute, Germany. This high resolution data was developed considering the world growth forced by level of atmospheric CO_2 according to the IPCC SRES A2 scenario, one of the most pessimistic projections. This data was further downscaled at the regional level using the Regional Climate Model PRECIS (Providing Regional Climates for Impact Studies) for the study area at 25x25 km. The downscaled data for the periods of 2020-29, 2050-59 and 2080-89 was used for the grid which falls nearest to the study locations in the three provinces. The predicted future climate scenarios were applied to the calibrated CERES-Rice model for study sites to determine the impacts on rice yield. The impacts were then determined by comparing the changes in the yield averaged for each of three decades compared to the yield as obtained for the actual daily weather data collected for 10 consecutive years for each of the sites.

RESULTS AND DISCUSSION

Model calibration

Experimental data obtained from the Rice Research Centers in Ubon Ratchathani, Khon Kaen and RoiEt were used for model calibration. The observed and simulated yield components at Ubon Ratchathani as presented in table 18.2 clearly indicate that the model results are in agreement with the field observations. Results are presented for two cases, seeding at normal dates and seeding at later dates. The late seeding means that the seeding was delayed by 10 days. The yield components simulated by the model indicate an error of 0.48% in grain yield and 3.50% in harvest index with seeding at normal dates. For the case of late seeding, the errors in simulated grain yield and harvest index were 3.13 and 5.26%, respectively.

Future climate scenarios

The CO2 concentration and the changes in average maximum and minimum temperatures and rainfall at Ubon Ratchathani, Khon Kaen and RoiEt for the periods 2020-29, 2050-59 and 2080-89 relative to the baseline data of 1980-89 are provided in table 18.3. Results clearly indicate that there will be an increase in maximum and minimum temperatures as well as rainfall at all three locations. At Ubon Ratchathani, the increase in maximum temperature will be as high as 3.51°C for 2080-89 and the increase in rainfall will be 45.2% for 2050-59.

Rice yield for the baseline year weather

The simulated rice yields for the baseline year 1980-89 were in good agreement at all three provinces for the observed and simulated weather

Anthesis Day (day after planting)	Simulated	Observed	% error
Rainfed at URRC	80	87	-8.05
Rainfed with late seeding dates at URRC	68	73	-6.85
By-product harvest (kg/ha)			
Rainfed at URRC	4,786	4,800	-0.29
Rainfed with late seeding dates at URRC	4,206	4,405	-4.52
Grain Yield (kg/ha)			
Rainfed at URRC	3,376	3,360	0.48
Rainfed with late seeding dates at URRC	2,805	2,720	3.13
Harvest Index			
Rainfed at URRC	0.414	0.40	3.50
Rainfed with late seeding dates at URRC	0.400	0.38	5.26

Table 18.2: Observed and simulated yield components at URRC for cultivar KDML105

URRC: Ubon Ratchathani Rice Research Center, Ubon Ratchathani, Thailand.

Time period	CO_2 conc. (ppm)	Ubon Ratchathani			Khon Kaen			RoiEt		
		Increase in			Increase in			Increase in		
		Tmax (°C)	Tmin (°C)	Rain fall %	Tmax (°C)	Tmin (°C)	Rain fall %	Tmax (°C)	Tmin (°C)	Rain fall %
2020-29	437	1.47	0.93	10.1	0.32	2.14	5.90	0.35	2.21	19.2
2050-59	555	1.72	2.14	45.2	3.3	3.15	2.60	1.59	3.2	40.5
2080-89	735	3.51	3.06	2.98	3.25	5.19	5.20	3.20	5.1	20.1

Table 18.3: Average climate change scenarios relative to 1980-89 weather

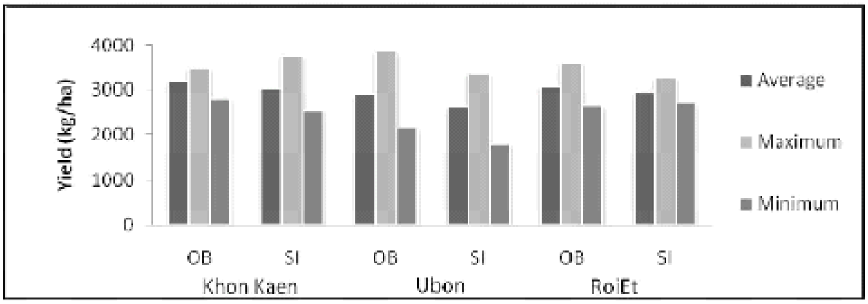

Figure 18.2: Simulated rice yields for the observed and simulated weather of 1980-89

Period	Yield (kg/ha)	Panicle (no./m²)	Grains (no./m²)	Total biomass (kg/ha)	Anthesis Duration (days)	Maturity duration (days)	Harvest Index
1997-06	2732	33.4	10613	6353	81	110	0.43
2020-29	2427	31.7	8990	6742	87	113	0.36
2050-59	2200	27.3	8149	6364	96	120	0.30
2080-89	1855	36.2	6869	6625	85	107	0.28

Table 18.4: Simulated yield and yield components at Ubon Ratchathani

data as shown in figure 18.2. The rice yields simulated by CERES-Rice averaged for the decade with observed weather data 3186 (± 220), 2908 (± 493) and 3081 (± 284) kg/ha are comparable with yields of 3022 (± 351), 2640 (± 503) and 2948 (± 196) kg/ha with the simulated weather data at Khon Kaen, Ubon Ratchathani and RoiEt, respectively.

Yield components for different climate scenarios

Table 18.4 presents the simulated yields and yield components for cultivar KDML105 for the observed and future climate scenarios at Ubon Ratchathani. Although the no. of panicles per unit area remains almost the same, the total no. of grains per unit area reduces considerably. This reduction is caused by the rise in temperature, which reduces the grain filling duration. The period between anthesis and maturity reduces for the future scenarios which affects the spikelet sterility and hence reduces the final grain yield. The harvest index also reduces with future scenarios indicating that although the total biomass yield remains almost the same, the grain yield reduces significantly.

	1997-2006 Yield (kg/ha)	2020-29		2050-59		2080-89	
		Yield (kg/ha)	Change (%)	Yield (kg/ha)	Change (%)	Yield (kg/ha)	Change (%)
Ubon	2732	2427	-11.16	2200	-19.47	1855	-32.10
Khon Kaen	2807	2101	-25.15	1883	-32.91	1901	-32.27
RoiEt	2128	1764	-17.11	1481	-32.11	1944	-8.64
Average	2556	2097	-17.81	1855	-27.59	1900	-24.34

Table 18.5: Simulated Rice Yield and Changes (%) for Future Climate Scenarios

Effect of predicted GCM scenarios on rice yield

The simulated rice yields for the observed weather (1997-2006) and predicted weather for 2020s, 2050s and 2080s and the changes in yields are given in table 18.5. There will be a significant decline in the yield for different climate scenarios. By taking the average of the three locations to represent the Northeast Thailand, a decline of 17.81, 27.59 and 24.34% in the 2020s, 2050s and 2080s, respectively is expected in the region. These results are similar to those reported by other researchers for China and India. Erda et al. (2005) found that there will be a change of -12.9, -13.6 and -28.6% in rainfed rice yield in China for the 2020s, 2050s and 2080s under the SRES A2 scenario. Similarly, Krishnan et al. (2007) predicted a change of -7.63, -9.38 and -15.86% in the rice yield for the GFDL, GISS and UKMO scenarios using ORYZA crop simulation model and a change of -9.02, -11.3 and 21.35% using INFOCROP crop simulation model for the future periods.

CONCLUSIONS

The study investigates the effects of climate change on rice production in Northeast Thailand using CERES-Rice crop growth model. The simulated weather data downscaled using regional climate model (PRECIS) was in good agreement with the observed weather in terms of seasonal pattern, indicating that PRECIS provided acceptable weather data for future scenarios. The CO2 concentration, temperature and rainfall are found to increase in future at the study area. The combined effect of these changes will be a decline in rice yield in the future. The vulnerability of rainfed rice production to climate variability and changes will lead to further large yearly fluctuations in the yield in the study area. It is necessary to identify and evaluate suitable adaptive measures and policies to counteract the impacts of future climate change on rice yield in the study area where rice is mainly grown for subsistence of the local people.

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19

VULNERABILITY AND ADAPTATION OF AGRICULTURE IN THE LOWER MEKONG BASIN TO CLIMATE CHANGE IMPACTS

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ABSTRACT

We examined the impact of climate change on the productivity of major crops grown in the Lower Mekong Basin using a model called AquaCrop. We divided the basin into 14 agro-climatic zones and selected a sub-catchment within each zone for setting-up the model. For the base case, the model has been set-up and validated for the data of 1996-2000. Climate change data used in the study are the future climate projection for two IPCC SRES[1] scenarios (A2 and B2) based on ECHAM4[2] General Circulation Model (GCM) from Max Planck Institute for Meteorology, Germany and downscaled to the Mekong region using the PRECIS[3] system. The model was run for climate scenario for the period of 2010 to 2050. Results suggest that yield of rainfed rice will increase for much of the basin except for a small part of Cambodia and Vietnam mainly in the A2 scenario, and about half of the basin in the B2 scenario. Shifting the planting date of rainfed rice can further increase the yield and minimize (no decrease) the impact in the areas where yield is adversely affected. Yield of irrigated rice would increase if irrigation requirement of the crop is fulfilled. The yield of maize will also not be adversely affected by the impact of climate change.

1 A2 and B2 are two climate change SRES (Special Report on Emission Scenarios) scenarios studied by the Intergovernmental Panel on Climate Change (IPCC). In brief, A2 is corresponding to a storyline of high population with slower per capita economic growth and technological change, and B2, a storyline of moderate population growth and economic development with less rapid and more diverse technological change.
2 ECHAM climate model has been developed from the weather forecast model of the 'European Centre for Medium Range Weather Forecast'
3 Providing Regional Climate for Impact Studies (PRECIS), a regional climate model developed by Hadley Centre

introduction

The Lower Mekong Basin (LMB) is one of the most dynamic, productive and diverse river basins in the world. It is home to approximately 65 million inhabitants, most of whom are rural poor with livelihoods directly dependent on the availability of water for the production of food. The population of the LMB is expected to increase from the current 65 million to about 90 million by 2050. The anticipated changes to climate and river flow are expected to affect agriculture and food production, the overall effect being to exacerbate the problems of supplying the increased food demand of growing populations. Thus, agricultural enterprises face greatly increased demand for food on the one hand and several threats to production on the other. Against this background, it is important to examine the potential impact of climate change on crop production which has direct consequences on the food security of the basin, and feasible adaptation strategies. In this paper, we examined the impact of climate change on the productivity of rainfed rice, irrigated rice and maize in the LMB and some adaptation strategies.

method

The LMB comprises the areas in Laos (198,750 Km^2), Thailand (182,850 Km^2), Cambodia (159,100 Km^2) and Vietnam (63,600 Km^2). The area is divided administratively into provinces in each riparian country. Based on the spatial average rainfall of the provinces estimated using the rainfall surfaces, provinces within the basin has been divided into zones. There are 3 zones in Laos, 4 zones in Thailand, 4 zones in Cambodia and 3 zones in Vietnam (2 in the Mekong Delta and 1 in Central Highlands). One province from each zone is selected to represent the group for simulation analysis (figure 19.1).

The AquaCrop model developed by FAO (Food and Agricultural Organization of the United Nations) was used to analyse the impact of climate change on rainfed rice, dry season irrigated rice and maize of the basin. These crops cover about 90% of the annual total harvested area of the basin. AquaCrop is a water-driven simulation model that requires a relatively low number of parameters and input data to simulate the yield response to water of most of the major field and vegetable crops cultivated worldwide. Its parameters are explicit and mostly intuitive and the model maintains sufficient balance between accuracy, simplicity and robustness (Raes et al., 2009; Steduto et al., 2009).

We ran the model in 14 locations for rainfed rice, 3 locations for irrigated rice (1 each in Laos, Thailand and Vietnam - due to unavailability of the yield data, site from Cambodia was not considered) and 6 locations for maize (2 in each country). In the model, we have used the crop calendar published by the MRC (Nesbitt, 2005) in defining the general crop growing period. Detailed soil data used in the MRC Decision Support System were used in this study. For the base case, the model has been set-up and validated for the data of 1996-2000. It is a well-established fact that the use of fertilizers are below the optimum level in the basin particularly in Laos, Thailand and Cambodia (Hasegawa et al. 2008, Fukai 2001). Harvest index is highly variable as a function of water availability and rice variety (Hayashi et al. 2007). To calibrate and validate the model, we tried to match the model yield with the observed yield by changing the planting date, fertilizer stress and harvest index but keeping them same for every year. Figure 19.2 compares the modelled average yield with the observed yield for rainfed rice for all 14 locations.

We modelled climate change as a change in climatic data and CO2 emission only. Climate change data used in the study are the future climate projection for two IPCC SRES5 scenarios (A2 and B2) based on ECHAM4 General Circulation Model (GCM) from Max Planck Institute for Meteorology, Germany and downscaled to the Mekong region using the PRECIS system.

For climate change scenarios of A2 and B2, we ran the model with generated climatic parameters such as rainfall, PET, maximum and minimum temperature for the period of 2010 to 2050 keeping all the soil, crop, and irrigation and management parameters the same as those used in the baseline condition. CO2 emission has also been considered varied from year to year for the simulation period according to SRES scenarios. For rainfed rice, we ran the model considering different adaptation scenarios such as shifting transplanting date of rice two weeks backward and two weeks forward from the date considered in the model setup for baseline condition, varying levels of fertilizer application and use of supplementary irrigation, etc.

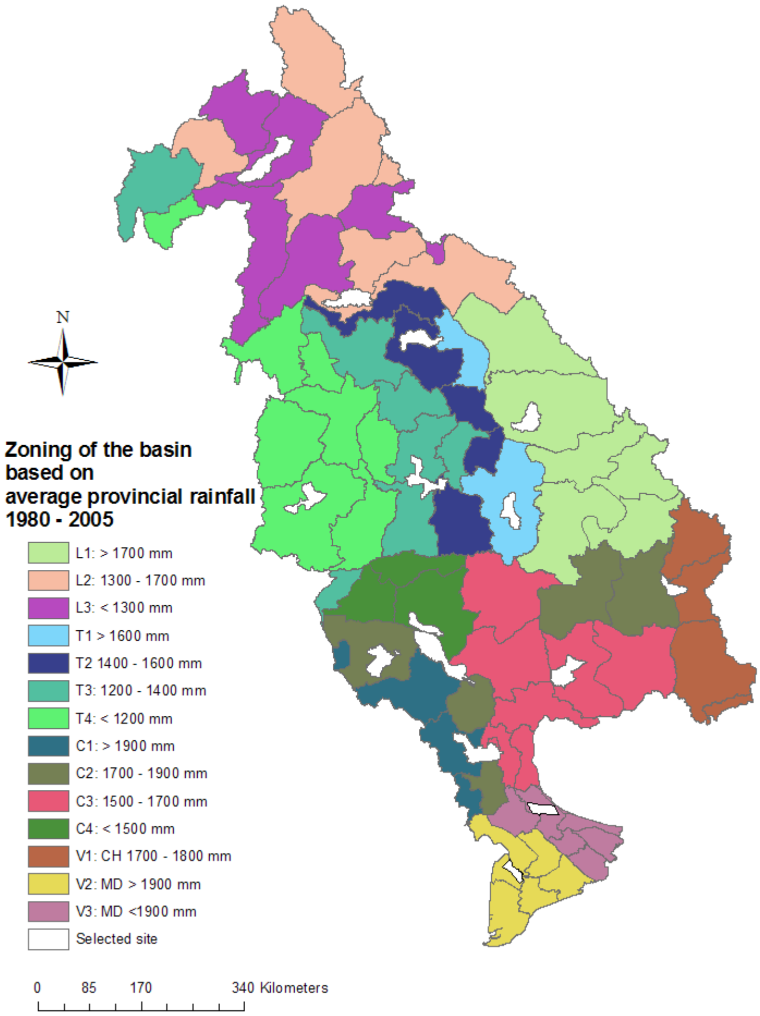

Figure 19.1: Location of the selected sub-catchment for simulation within zones (L1, T1, etc.)

RESULTS

The average yield of rice for the baseline, A2, and B2 scenarios for all locations is shown in figure 19.3. Figure 19.4 shows the percentage change of yield from baseline for A2 and B2 climate scenarios after extrapolating the simulation results to the respective agro-climatic

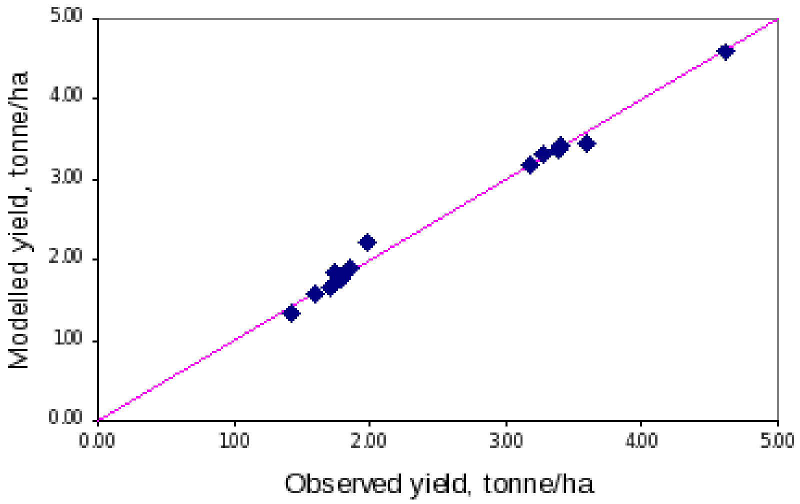

Figure 19.2: Comparison of modelled yield with the observed yield of rainfed rice

zones. Results suggest that yield of rice will increase for much of the basin except for a small part of Cambodia and Vietnam mainly in the A2 scenario, and about half of the basin in the B2 scenario (all sites in Cambodia and Vietnam and one site in Laos). The increase is higher in Laos (up to 28.1%) and Thailand (up to 17.2%) and for A2 scenario than the B2 scenario. The reduction of yield is highest (14.2%) in the site C1 followed by C4 (5.1%) for A2 scenario. For B2 scenario, the reduction is highest in site V3 (11.0%) followed by V1 (10.1%) and C3 (8.4%). The results of this study are broadly similar to the studies by Eastham et al., (2008), Chinavanno (2004), and Hoanh et al. (2003).

Shifting the planting date of rainfed rice can increase the yield and minimize (no decrease) the impact in the areas where yield is adversely affected. Fertilizer use in the basin is currently at sub-optimal level (i.e. there is fertility stress) particularly in the areas in Laos, Thailand and Cambodia (Fukai, 2001). Reducing the fertility stress by 10% can increase yield by about 3-4%. Providing supplementary irrigation can further enhance yield particularly in the Mekong Delta. The analysis suggests that shifting transplanting date with reduced fertility stress can offset the negative impact of climate change on yield in the affected areas.

The impact of climate change on the yield of irrigated rice is shown in figure 19.5 for three locations in the basin. Yield will increase more than 20% for A2 scenario and more than 10% for B2 scenario in all

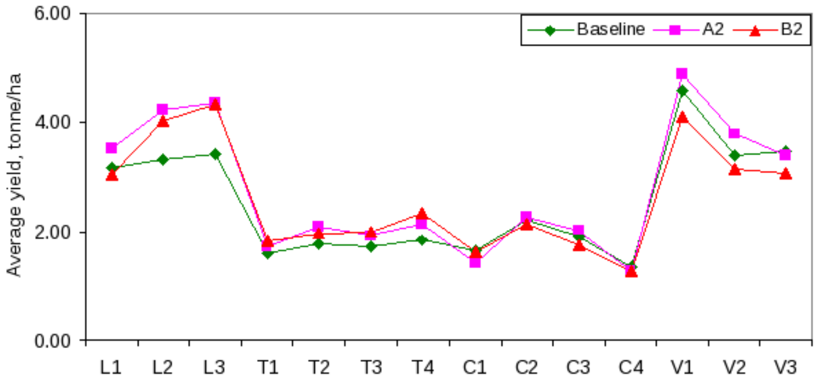

Figure 19.3: Comparison of average yield of rainfed rice for baseline, A2, and B2 scenarios

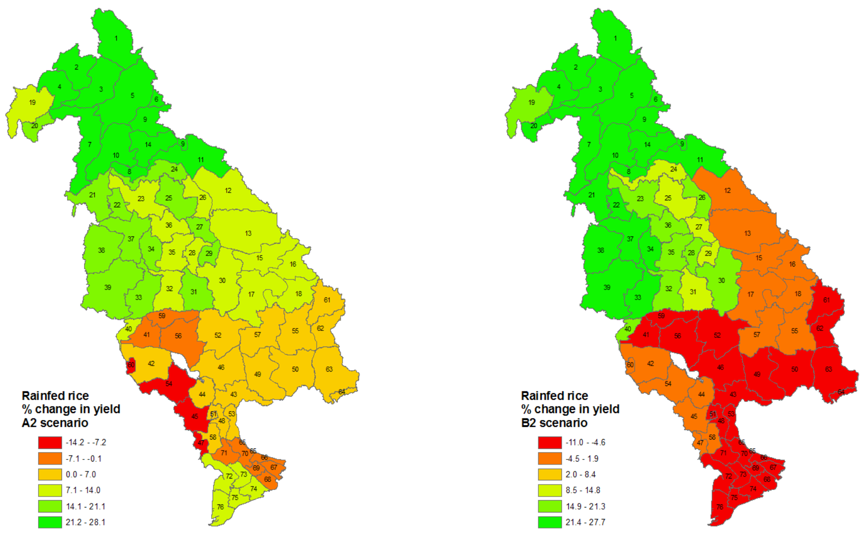

Figure 19.4: Change in yield of rainfed rice for A2 and B2 climate scenario

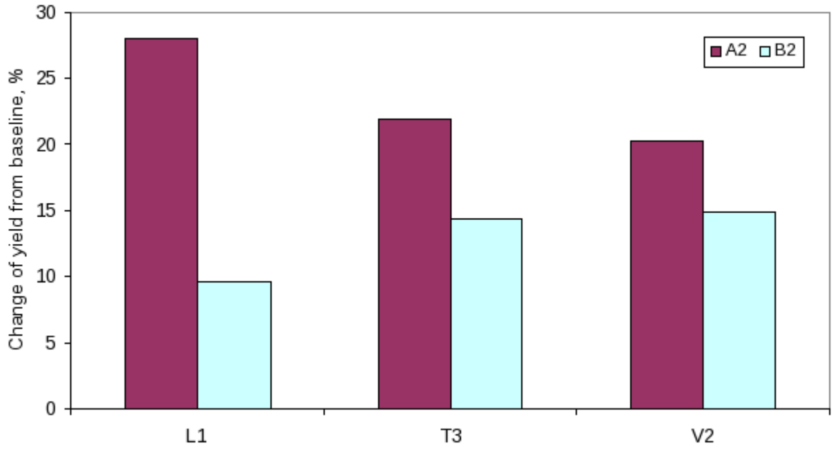

Figure 19.5: Change in yield of irrigated rice for A2 and B2 climate scenario

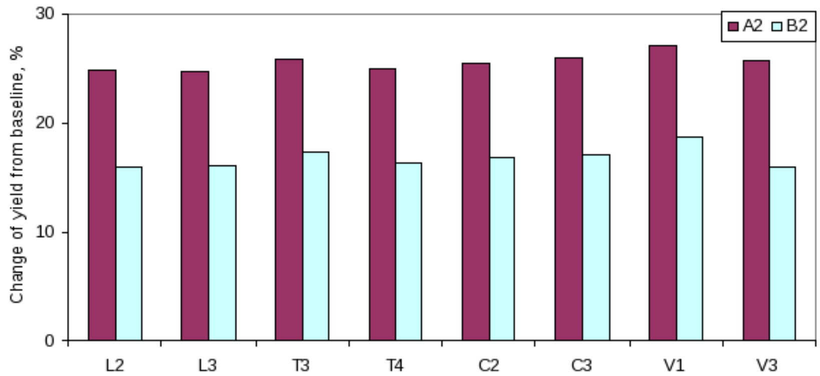

Figure 19.6: Change in yield of maize for A2 and B2 climate scenario

locations if irrigation requirement of the crop is fulfilled. However, the irrigation requirements will increase due to increase in potential evapotranspiration and hence diversion of irrigation water from the river would increase.

Figure 19.6 shows the impact of climate change on the yield of maize. As the figure suggests the yield of maize may increase by about 25% and 15% compared to the baseline yield respectively for A2 and B2 scenario across the basin. The increase is mainly due to increased CO_2 concentration in the atmosphere.

CONCLUSION

The results suggest that crop productivity is unlikely to be adversely affected by the impact of climate change. Rather there is a potential that yield may increase due to climate change particularly in the upper half of the LMB. Over the last ten years, crop production and productivity has increased everywhere in the basin. The current rate of increase is considerably greater than the rate required to feed the expected extra population by 2050. Combined with the expected increases under climate change scenarios, it appears unlikely that food security, in terms of the total food available, will be threatened for at least the next few decades. However, food security for all individuals also requires that the production is distributed equitably: this issue is beyond the scope of our study. The study does not take into account the impact of extreme events such as floods, extreme drought, sea level rise, cyclones, storm, etc. which may become more frequent with higher intensity due to climate change.

ACKNOWLEDGEMENT: Funding from AusAID and Water for Healthy Country of CSIRO to undertake this work is gratefully acknowledged.

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20

POTENTIAL CLIMATE CHANGE INDUCED IMPACTS ON AQUACULTURE IN THE LOWER MEKONG BASIN: THE CHALLENGES AND OPPORTUNITIES

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ABSTRACT

The Lower Mekong Basin (LMB) spreads across an area of 606,000 km² covering parts of Cambodia, Lao PDR, Thailand, and Vietnam. The basin is one of the most biologically diverse fresh and brackish water ecosystems in the world providing a major source of protein and basic livelihood for 65 million people with its annual fish catches of approximately 1.5 million tons. Cage, pond, pen and rice-field fish culture is widely practices in its rivers, tributaries and other water resources. Shrimp and catfish (Pangasius Sp) are two of the major aquaculture products of LMB in Vietnam. While catfish production in 2007 was 1.2 million tonnes, valued at USD 1 billion, shrimp production reached 300 tonnes. This billion dollar industry in the LMB provides livelihoods for a vast number of people, a significant proportion of which are rural woman. Climate change might have both negative and positive impacts on aquaculture in the LMB region. The potential negative impacts of climate change as well as the opportunities provided by climate change on aquaculture development in the LMB are discussed in this paper. The paper elucidates potential adaptive measures that are relevant to aquaculture and analyzes the wide array of available adaptive measures.

INTRODUCTION

The Lower Mekong Basin (LMB) spreads across an area of 606,000 km² covering parts of Cambodia, Lao PDR, Thailand, and Vietnam. The basin is one of the most biologically diverse aquatic ecosystems, comprising both freshwater and brackish water environment that provides livelihood for 65 million people. With its annual fish catches of approximately 1.5 million tons, LMB provide a major source of animal protein to a vast population. Both pond and cage fish culture is widely practices in or in the vicinity of the river and its tributaries. Shrimp and catfish (Pangasius sp.) are two of the major aquaculture products of LMB in Vietnam. While catfish production in 2007 was 1.2 million tonnes, valued at USD 1 billion shrimp production reached 300 tonnes.

The global level impacts of climate change on aquaculture and fisheries production are aptly described by the FAO (2008, 2009). FAO (2008) divided effect of climate change impacts on fisheries and aquaculture into two groups: (1) biophysical impacts such as decline yield and product quality due to increased temperature, and (2) socio-economic impacts such as reduced farm income and national GDP. De Silva and Soto (2009) discussed direct (temperature, flooding, extreme events etc.) and indirect (reduction in fishmeal supply etc.) impacts and conclude that climate change might alter the production process but it will still remain the predominant economic activity in the tropical and sub-tropical areas. The Mekong River Commission (MRC) evaluated potential impacts of climate change in the LMB and analyzed potential adaptive measures in the LMB countries (MRC, 2009). MRC suggested that adaptive measures such as introduction of high-temperature tolerance species, moving from rice monoculture to fish-rice rotation systems, infrastructure development considering sea level rise, building storm shelters and establishing natural ecological reserves (MRC, 2009). Alison et al (2009) compared fisheries sector vulnerability of 139 countries' to climate change in 139 countries taking exposure, sensitivity and adaptive capacity into account. They include Cambodia as one of the most vulnerable countries. The challenges posed and opportunities that will be created for LMB aquaculture by climate change are discussed in this paper.

Characteristics of aquaculture systems

Aquaculture is defined as the cultivation of aquatic organisms in fresh, brackish and marine waters. The principles of cultivation of aquatic plants are similar to agricultural crop production and culture of aquatic animals is similar to that of animal husbandry. However, aquaculture systems have specific characteristics that separate it from its counterparts of agriculture and animal husbandry in several ways. First, over 100 diverse aquatic species, both carnivorous and omnivorous, are used in fish culture. Second, the production process involves the human

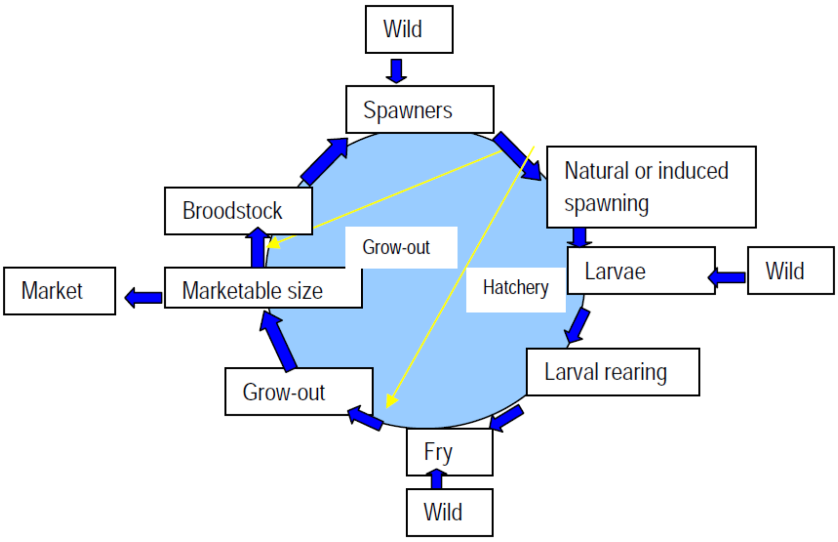

Figure 20.1: Schematic production cycle of aquaculture and control points

control of the life cycle (figure 20.1). Third, the degree of human control is species-specific. For example, humans control either the whole life cycle (e.g. tilapias and carps) or part of the life cycle (e.g. Black tiger prawn (Penaeus monodon) broodstock are collected from the wild and snakehead (Channa sp) and grouper fish fry are collected from the natural waters). While animal husbandry mainly targets homeothermic (warm blooded) animals, aquaculture uses poikilothermic (body temperature is similar to the ambient temperature). Hence the reproductive and growth processes are influenced by water temperature.

Aquaculture differs from the fisheries on the degree of human intervention (Anderson, 2002; Asche and Khatun, 2006). While aquaculture industry is production oriented and the fisheries are "hunting" oriented. Hence, aquaculturists have control over the production process e.g. through artificial fluctuation of water temperature to induce spawning behavior; manipulation of feed quality and quantity for enhance growth and to obtain desirable product quality. The degree of human intervention and control in aquaculture is governed by the production intensity. The extensive aquaculture systems, which are entirely dependent on the natural feed supply, have a minimal human control and similar to stock enhancement processes of inland fisheries. In both semi-intensive and intensive aquaculture, humans control reproductive processes, stocking sizes and densities, water and feed use and harvesting strategies that match market demand.

The aquaculture production process is governed by biological, environmental, technological, social, economic and marketing factors. Biological governing factors include reproductive mechanisms, nutritional requirements, and respiratory mechanisms (air breathing or water breathing). The factors such as dissolved oxygen content of water, temperature and salinity and absence of toxic elements govern the culture environment, and technological factors such as breeding, larval rearing, grow-up and health management technologies governs the expansion of aquaculture industry. Socio- economic factors such as social acceptability and affordability, access to market and cost-benefit issues override others factors influencing the success of the aquaculture industry.

current status of the global aquaculture industry

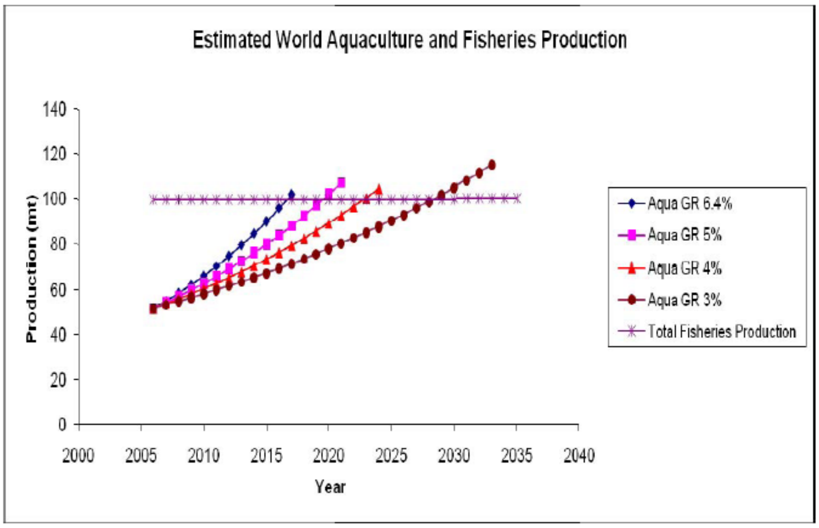

Figure 20.2: Estimated growth rate of world aquaculture at different growth rates

World aquaculture production in 2006 was 52 million tonnes of aquatic animals with a value of US$78.8 billion and including aquatic plants, world aquaculture production in 2006 was 66.7 million tonnes worth US$85.9 billion (FAO, 2009). Aquaculture production in the Asia-Pacific regions accounted for 89%t of production by quantity and 77% of value. China, being the main producer, contributed 67%t of the total quantity and 49%of the total value of aquaculture production. World aquaculture

Region	Culture area	As a %	Production	As a %
Mekong delta	554,800	91.6	287,700	81.2
Rest of Vietnam	95,900	8.4	66,900	18.8
Total	650,700	100	354,600	100

Table 20.1: Shrimp culture in Mekong Delta, Vietnam (2006) (Source: Nguyen Van Trong, 2010)

grew at a rate of 5.6% from 2002 – 2006 and if this trend continues, aquaculture will surpass world fisheries production within the next two decades(figure 20.2).

AQUACULTURE PRODUCTION IN THE LOWER MEKONG SUB-REGION

The aquatic animal species cultured in the Mekong delta are diverse. While Lao PDR, Thailand and Vietnam mainly use hatchery produced seed for stocking, Cambodia rely on wild seed collection. Rural aquaculture is a popular livelihood activity in the inland areas of the LMB. MRC (2002) estimated that the Mekong Delta of Lao PDR, Cambodia, Thailand and Vietnam produced 5,738, 14,100, 68,000, and 171,000 freshwater fish annually, respectively. The estimated value of aquaculture products were 7, 17, 20.4, and 244 Million US$, respectively. The estimated number of rural households involved in aquaculture in Lao PDR, Thailand and Vietnam was 0.7, 2.6, and 2.7 million in 2002. In 2002, Thai Department of Fisheries reported that aquaculture production in the Mekong region of Thailand was 61,885 tonnes but MRC claimed that this was an under estimation (Na Mahasarakarm, 2007). Pond aquaculture is common in NE Thailand where 148,443 farmers used 27,513 ha to culture fish in 2002. Aquaculture is also practiced in the paddy fields (6,742 farmers, 5,835 ha in 2002) and ditches (Hortle, 2007) The highest commercial aquaculture production is taken place in the Vietnamese Mekong Basin. Since 2006, around 1.1 Million metric tonnes and 350,000 – 375,000 tonnes per annum of Pangasid catfish and brackish-water shrimp, respectively, in the Mekong Delta of Vietnam (figure 20.3 and table 20.1). Both catfish and shrimp production has reached the upper limit of the resources and environmental and market constraints. However, Vietnam Mekong delta plays of major role in shrimp production in both culture area (92%) and percentage of production (81%)

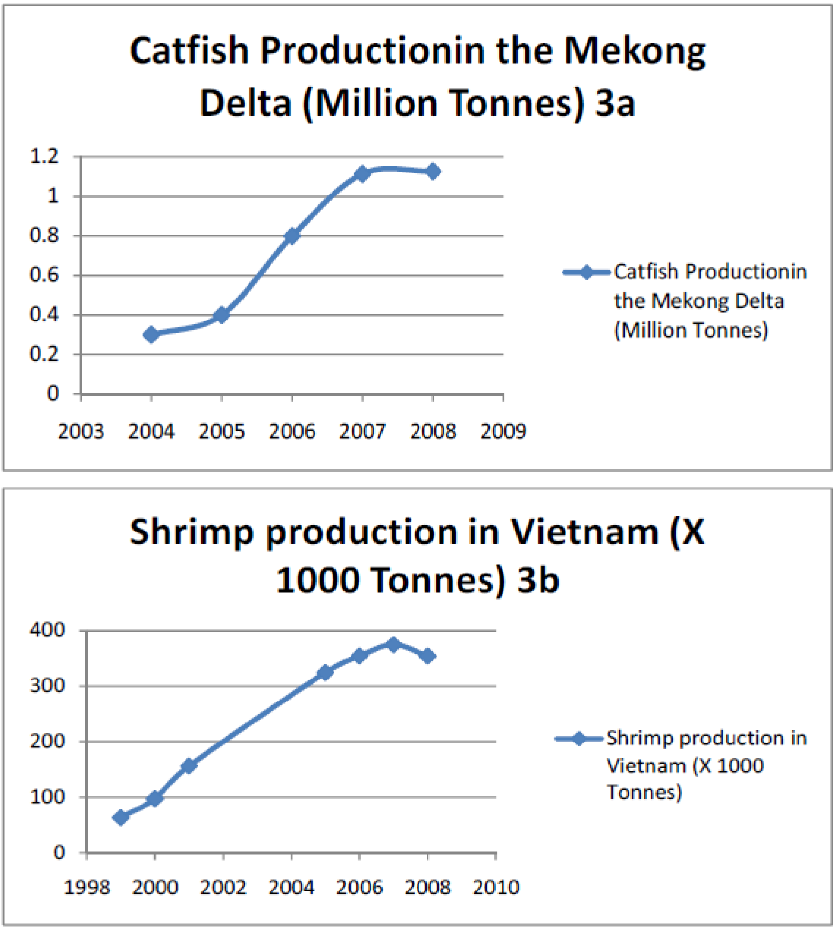

Figure 20.3: Catfish (a) and shrimp (b) production trends in the Mekong delta - Vietnam (Source: Nguyen Van Trong, 2010)

factors affecting the resilience of aquaculture systems

The pressure-state-response (PSR) model has been widely used in environmental monitoring (OCED, 1993; Fleischhaue et al, 1997). The concept has been applied to evaluate the driving forces-pressure-state-impact-response (DPSIR) model to analyze the dynamics of small livestock production systems. Using a similar approach, the systems dynamics of aquaculture systems is shown as a conceptual stimuli-pressure-response-state (SPRS) system in figure 20.4.

Cheap wild fish availability is a deterrent of aquaculture development. However, wild fish play an important role in the nutrition of the poorest sectors of the society (MRC, 2002). The major stimuli for aquaculture are consumer demand and relatively high farm-gate price over other food commodities. Both the shrimp and catfish farming booms started in the Mekong delta mainly due to export demand. Tilapia, dubbed as the poor man's fish in 1980s, became an exportable commodity in 1990 decade due to demand from both exporters and local supermarkets.

The pressures that shape the aquaculture industry are:

1. environmental factors such as water quality, temperature and the dissolvability of oxygen;
2. input limitations such as high quality feeds;
3. pathogens and diseases;
4. negative images due to negative environmental impacts from some forms of aquaculture e.g. shrimp cultures in mangrove areas, waste disposal etc. and market and taxation pressures.

However, aquaculture farmers have shown a great resilience to much of these pressures by changing the state of the system. Some examples are summarized in table 20.2.

climate change predictions for the lower mekong basin

Among the emission scenarios of IPCC, A1B scenario describes a situation which is not heavily reliant on a particular energy source i.e. diversification of energy sources. MRC (2009) reported the following environmental irregularities predicted by IPCC under scenario of A1B for the LMB region:

1. A LMB- wide temperature increase of 0.79°C (greater increases in the north of the basin); A longer hot period and a shorter cold period; coastal areas of Vietnam by 1.5 °C by 2070

Driver/ threat	Example	System change	Reference
Aquatic pathogenic organisms	Thailand – Tiger prawn (Penaeus monodon) diseases make financial losses	1. Develop recirculation system; relatively low stocking density 2. Change the species to while leg shrimp (Penaeus vannamei)	FAO, 2004; Pers Com with shrimp farmers in Thailand
Avian influenza	Chicken-fish integration was threatened by chicken flu in Thailand	3. Farmers become contract farmers to receive certified disease free chicken from the companies +develop closed system for chicken grow-out stage + continue with integration of fish	Pers. Com with farmers in Saphanburi province, Thailand
Regulations	Cambodia – GOV banned giant snakehead culture	4. Culture omnivorous species – Pangasius catfish and high value native carp species (Leptobarbus hovoeni; Barbichthys altus)	Edwards, 2008
Water pollution	Catfish cage culture in Mekong river and tributaries face economic losses due to slow growth + high mortality + disease outbreak + water pollution	5. Change cage culture to pond culture system	Phoung et al, (2004)
Seasonal flooding	Aquaculture in low-lying area is threatened by flooding as fish escape	6. Raise net and other type of barriers to stop fish escaping	Pers. Obs.
Salinity intrusion	Salinity intrusion lower Mekong delta in Vietnam reduce opportunity for growing two crops	7. Rice-shrimp rotation. This provided more income than rice only	White, 1999; 2002; Gowing et al, 2006

Table 20.2: Some examples of the resilience of aquaculture systems

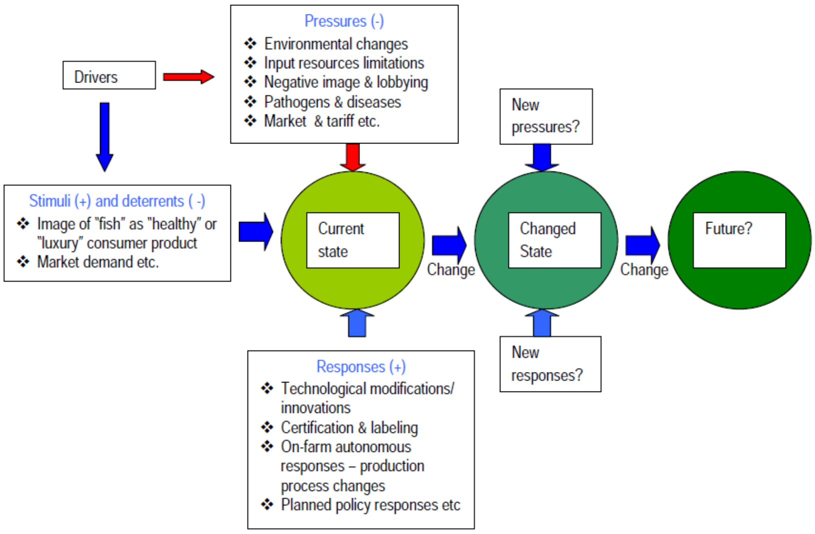

Figure 20.4: Schematic representation of stimuli-pressure-response-state model for the pattern of change in aquaculture systems

2. Increases in annual precipitation (0.2 m = more than 15.3%, mainly during the wet season precipitation);
3. Increase in dry season precipitation in northern catchments and a decrease in dry season precipitation in southern catchments;
4. An increase in total annual runoff of 21% (maintain or improve annual water availability with the exception of isolated areas of northeastern Thailand and Tonle Sap);
5. An increase in flooding, especially in downstream catchments of the Mekong;
6. Increases in capture fisheries through increased storage volumes and levels of Tonle Sap, a major source of capture fisheries
7. Increase (3.6%) in agricultural productivity
8. Overall increases in food scarcity due to increased population growth (predicted increases in fisheries and agriculture might dependent on whether reduced water flow in the dry season negatively affects fisheries and whether the floods damage the crops)

Potential sea level rise would affect Cambodia, Thailand and Vietnam. The Cambodian Ministry of Environment (2002) reported that if the sea level rose by 1m (by 2100), a 44 km^2 stretch of the Koh Kong province would be permanently under sea water. This includes mangrove forests (70%), shrimp farms (8%), grasslands (6.8%), townships (6.3%) and forests (4.1%). Sea level rise will increase saltwater intrusion into the estuaries and low lying areas both in Thailand and Vietnam, which is taking place now in the dry season. MRC (2009) claimed that this will negatively affect aquaculture in Thailand, as the industry is spread over mudflats and mangrove areas. About 36, 000 km^2 of the Mekong delta of Vietnam is predicted to be inundated with a 1m sea level rise (90% of total 40.000 km^2 area), where aquaculture plays a major role in the national economy.

Increased evepo-transpiration is expected to decrease water storage of reservoirs and rivers. MRC (2009) quoted the results of a study on Thailand's Sri Nakarin Dam (outside the Mekong Basin) that predicted shortages of water under a doubling of CO2 level scenario.

Extreme weather events, flooding, and drought might negatively affect both aquaculture and agriculture. In 2006-07 Vietnam experienced typhoons, floods and droughts that caused severe property, infrastructure aquaculture, agricultural and livelihood losses (Nagothu et al, 2009). Increased water temperature, as well as seawater acidification, is expected to affect coral reefs negatively.

CLIMATE CHANGES IMPACTS ON AQUACULTURE

Climate change can have both negative and positive impacts on the aquaculture industry. Widely mentioned negative impacts are flooding, changes in water salinity, new pathogen development, reductions in input supply etc. The positive effects such as increased growth rates of animals due to increased water temperatures and expansion of the industry due to increased water supply are frequently mentioned. These impacts are aptly described by various authors e.g. Easterling et al, 2007; FAO, 2008; De Silva, 208: De Silva and Soto, 2009; and MRC, 2009. Since the degree of control over the production system is an important characteristic of aquaculture systems, this characteristic would provide a chance to convert potential climate threats to opportunities.

Direct drivers and potential responses:

It has been postulated that climate change might negatively affect aquaculture in the LMB directly via (1) increased water temperature,(2) increased precipitation and flooding, (3) salinity intrusion, and (4) extreme whether events such as typhoons. The predicted increases (+)

and deceases (-) of these events in the different catchment areas are shown in table 20.3.

1. Potential responses to water temperature increases

   Figure 20.5 shows the diurnal temperature dynamics of small-shallow (200 m^2; 1 m in depth) fish ponds at the Asian Institute of Technology in the summer of 1995. The surface temperature increased to as high as 36 °C in the day time. A temporary thermocline develops in the daytime but it collapse during the night time. Diurnal dissolve oxygen (DO) dynamics also follows the temperature curve with a supersaturated peak around 16 – 17hr. This thermocline development helps to maintain the DO regime of the whole ponds by bringing supersaturated surface layers of the water to the pond bottom during the nighttime. The temperature at 90 cm remains below 30 degrees and this is suitable for the maximum rate for the growth of tropical fish. Deepening the fish pond to 2 – 3 m will provide an opportunity to counteract the surface temperature increases. However, increased temperatures can affect the spawning performance. This has been observed by the commercial tilapia hatchery managers that the egg production of Nile tilapia decreases during the summer months. The hatchery operators either shut down the operation during the summer months or accept low egg production to breakeven the costs. However, these problems will not affect the fish species that are maintained inside a hatchery under controlled temperature conditions and induce spawning process hormonally.

2. Responses for increased precipitation and flooding

   Fish farmers operating in the flood prone areas have developed strategies to live with floods (Lusterico, 2006).The current practices to cope with floods are either protecting culture facilities while increasing the dyke height or raising net barriers to avoid fish escape and prevent flood waters from flowing through the farm. However, the latter procedure risks the introduction of pathogens. The solution might lie in our ability to predict floods early to take protective measures, development of a cropping calendar to harvest fish before flooding events, and investing on aquaculture development in relatively flood-free zones of the basin. Autonomous adaptations such as raising farm dykes will block the flood water receding paths, making the situation worse. The need for developing planned adaptation measures using topo-

LMB Catchment Area	T	Ann Prc	Dry Prc	Ann Rnf	Dry Rnf	Fd Pot	Pek Flw	Fd Dur	Fd Ara	Dry Min Flw	Saline Intr
Moung Nouy: Northern Lao PDR	+	+	+	+	+	+					
Luang Prabang: Northern Thailand and Northern Lao PDR	+	+	+	+	+	+					
Vientiane: Northern Lao PDR and of Northeast Thailand	+	+	+	+	+	+					
Tha Ngon: Central Lao PDR	+	+	-	+	+	+					
Nakhon Phanom: Central Lao PDR and	+	+	-	+	-	+					
North-east Thailand	+	+	-	+	+	+					
Mukdahan: Southern Lao PDR and Northeast Thailand	+	+	-	+	-	+					
Ban Keng Done: Central Lao PDR	+	+	-	+	+	+					
Yasothon: Northeast Thailand	+	+	-	+	+	+					
Ubon Ratchathani: Northeast Thailand	+	+	-	+	+	+					
Pakse: Southern Lao PDR and Northeast Thailand	+	+	-	+	-	+					
Se San: Southern Lao PDR, NE Cambodia & Central Highlands of Vietnam	+	+	-	+	-	+					
Kratie: Southern Lao PDR and Central Cambodia	+	+	-	+	-	+	+	+	+	+	
Tonle Sap: Central Cambodia	+	+	-	+	+	+		+	+		
Phnom Penh: South-eastern Cambodia	+	+	-	+	-	+			+		
Border: Southern Cambodia and South Vietnam	+	+	-	+	-	+			+		
Delta: South Vietnam	+	+	-	+	-	+			+	+	-?

Table 20.3: Predicted changes of selected physical factors in the LMB catchment areas due to climate change (Modified after MRC, 2009)

T = Temperature; Ann Prc = Annual Precipitation; Dry PRC = Dry Season Precipitation; ; Ann Rnf = Annual unoff; Dry Rnf = Dry Season Runoff; Fd Pot = Fllod Potential; Pek Flw = Peek Flows; Fd Dur = Flood Duration; FD Ara = Flooded area; Dry Min Flw = Dry Season minimum flow; Saline intr = Salinity Intrusion

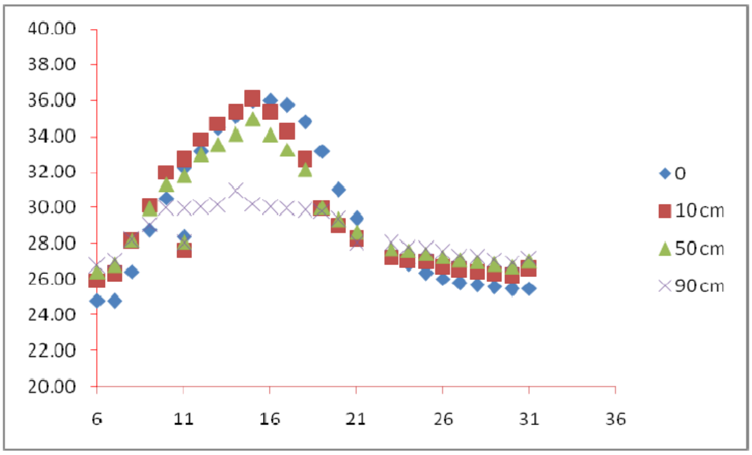

Figure 20.5: Temperature dynamics of tropical fish ponds (Data source: AIT unpublished data)

logical maps, identifying flood reseeding pathways and building protective infra-structure might alleviate the situation.

The positive effects of floods are increased water availability. This would provide an opportunity to store flood water and expand aquaculture to the relatively upland areas of the basin.

3. Responses to salinity intrusion

Flood gates have been constructed in the Mekong delta to reduce salt water intrusion. White et al (1999), White (2002) and Gowing et al (2006) discussed the negative effects of the flood gate construction on the acid sulfate soil which promotes acidification of soil by denying tidal-driven acid neutralization processes, making water acidic and negatively impacting fish migrations. If these gates must be constructed, they should be built above the areas of acid sulfate soil so that both rice and shrimp farmers can benefit.

Salinity intrusion in the Mekong Delta has helped farmers to receive suitable water above 5 PSU and to enhance their income by practicing rice-shrimp rotation (Gowing et al, 2006; Son et al, 2010). These innovative rice farmers have shown an example of the best way to cope with salinity intrusions by changing cultural practices. MRC (2009) claimed that sea level rise will inundate around 38,000 km2 in Vietnam and 44 km2 of Koh Kong province (Cambodia) from a depth of 1 to 5 m. If this ever takes place, this will provide new opportunities to both Vietnamese and Cambodian farmers to develop new cultural practices and expand cage and pen fish farming practices.

It is known that fish like Nile tilapia can grow well in 15 PSU salinity, Recently, it has been shown that Pangasius hypopthalamus (Tra catfish) grows well at 12 PSU (Castaneda et al, 2010). More research into salinity tolerance of commercially valuable species is warranted.

4. Extreme whether events

   It is impossible to imagine a way out of this situation. The only viable option would be develop the confidence of Insurance companies to develop insurance policy options for emergency. Private Banks in a few Asian countries, including Vietnam, have started aquaculture insurance (FAO, 2006).

Indirect drivers:

The major indirect drivers would be either to reduce or increase input supplies and input prices. An important consideration in the LMB region is the supply and price of: (1) fish seed; (2) fishmeal; and (3) manure and fertilizer.

Except Cambodia, all other countries in the region rely on hatchery-bred seed supplies. Cambodia can easily adopt the hatchery technologies developed in the region.

It is highly unlikely that the fishmeal supply would greatly hinder aquaculture development as the major culture species are omnivorous. Commercialization of plant protein isolate production technologies will grab the attention of aquaculture nutritionists in the years to come and this will most probably reduce the reliance on fishmeal.

Similarly, manure availability will continue through animal husbandry and climate change might not hinder inorganic fertilizer availability.

ADAPTATION MEASURES SUGGESTED BY VARIOUS AUTHORS AND AGENCIES

MRC (2009) recommended the development of strategies for multipurpose use of water resources in the national development activities in Lao PDR i.e. integrated hydropower, irrigation, water supply, fisheries, aquaculture etc. The government of Vietnam, the only LMB country which has suggested adaptation measures for specific for aquaculture, proposed the following (MRC, 2009):

- Introduce and develop economically valuable aquaculture species/-varieties that could adapt to high temperature, (e.g. sugpo prawn, green clawed crayfish, lobster, white bass, black bass, etc)
- Increase the depth of lakes and ponds to create suitable temperature and mitigate losses due to increased evaporation
- Change cropping pattern e.g. convert rice monoculture to fish to rice-shrimp rotation system
- Include sea level rise and increased temperatures into planning and design of infrastructure, quays, ports, warehouses, etc
- Build storm shelter/port systems along the coast and islands
- Establishing natural ecological reserves, especially coral reefs and atolls

Nagothu et al (2009) conducted a stakeholder analysis to evaluate the views of farmers, aquaculture managers and other interest groups on the climate change impacts on Pangasid aquaculture in the Mekong delta. The participants saw that climate change was a threat to catfish faring and raised the following concerns and suggested some adaptation measures:

- Concerns of catfish farming stakeholders:
- Sea level rise and salinity intrusion are major threats. This will reduce the area available for freshwater fish culture
- Flooding, early or intense rainfall, increased water temperatures in summer make fish are vulnerable to disease outbreaks and growth rate reduction
- Infrastructure destruction by extreme weather events
- Increased temperature and changes in water quality will lead to flesh color changes from white to yellow
- Reduced production and income

Suggested adaptation measures by the stakeholders of catfish farming (Nagothu et al, 2009):

- Foe water quality maintenance:
  - Add salt and lime to control water pH (in acid sulphate soils)
  - Chemical treatment for preventing color changes in fish flesh

    - Use probiotics to improve water quality
    - Improve irrigation canals to access to better quality water

- For disease control
    - Development of effective vaccination and antibiotic use to prevent diseases
- To reduce stresses
    - Reduce stocking density (to avoid stress)
    - Improve feed quality (to reduce feed stress)
- To improve survival and growth rate
    - Improve seed quality
    - Selective breeding to achieve faster growth
- For flood and salinity intrusion control
    - Develop aquaculture zones
    - Increase dyke height and build new dykes
    - Adjust cropping calendar to avoid saltwater intrusion period
- To enhance sector/ farmer awareness
    - Training and capacity building

CONCLUSIONS

The adaptive measures of the aquaculture sector to deal with potential climate change scenarios should be analyzed in different scales: (1) Farm level autonomous adaptation measures such as dyke-building to protect from flooding, reduce seepage losses during drought and hatchery design to control water temperature; (2) Autonomous or planned adaptation measures (opportunities) at wetland level such as pen culture in newly inundated shallow coastal areas; and (3) Planned measures at basin (regional) level to adapt to changes of water quality parameters such as salinity; and (4) Adaptive measures to counteract global level impacts such as potential decline of fishmeal availability.

There is a wide array of adaptive measures suggested by different authors. However, these measures should be critically evaluated for their strengths and weaknesses, and threats and opportunities (SWOT) at the regional, national and local levels. It can be expected that the demand for cultured fish will continue to increase due to global overfishing and new overseas markets will emerge in the future. Aquaculturists in the LMB region will be able to capture this opportunity by developing carefully and collectively formulating adaptive measures.

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21

MEKONG FISH BIODIVERSITY UNDER MULTIPLE STRESSES

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The Mekong, the longest river in Southeast Asia, covers all types of ecosystems in the world except desert. Multiple kinds of aquatic habitats including river mainstream and tributary, estuary, floodplains, wetlands, highland streams, deep pools, lakes reservoirs and caves, support it the largest fisheries in the world (Rainboth 1996), and the diversity (per unit area of catchment) is roughly three times that recorded for the Amazon River basin and is well in excess of that normally associated with coral reefs (Coates, 2009).

FISH BIODIVERSITY IN MEKONG

The Mekong is one of the largest rivers in the world. It originates from the Qinghai-Tibetan Plateau, and flows approximately 4,880 kilometers through China, Myanmar, Thailand, Cambodia, Laos, and Vietnam where it finally discharges into the South China Sea. Mekong has been divided into two parts: the Upper Mekong and the Lower Mekong. The Upper Mekong, also known as the Lancang River, is located within China (Qinghai and Yunnan Provinces). The Lower Mekong basin, covering 76 percent of the total Mekong basin, comprises 97 percent of the area of Laos, 86 percent of the area of Cambodia, 36 percent of the area of Thailand, and 20 percent of the area of Vietnam (Quang & Nguyen, 2003).

Fish Biodiversity in the Upper Mekong

Studies on fish species in the Upper Mekong began in the 1950s (e.g. Cheng 1958; Zhang 1962). Besides some scattered published materials, two monographs, ''Fishes in Yunnan'' (Chu and Chen 1989, 1990, mainly on Yunnan part) and ''The Fishes of Qinghai-Xizang Plateau'' (Wu and Wu 1991, mainly on Qinghai and Xizang parts) supported fish information in the Upper Mekong. Based on a recent review paper "Fish and fisheries in the Upper Mekong: current assessment of the fish community, threats and conservation" (Kang et al., 2009a), altogether 173 freshwater fish species and subspecies among 7 orders, 23 families and 100 genera are distributed in the Upper Mekong, including 87 endemic species and subspecies. The most species-rich order is Cypriniformes accounting for 72.8% of the population. Schistura in Balitoridae and Cyprinus in Cyprinidae are two genera with the highest species numbers in the basin. In total 14 fish species in the Upper Mekong have been identified as endangered (Yue and Chen 1998). Under cluster analysis, fish fauna in the Upper Mekong was featured by a pattern as 'Four parts (headwater, upper reach, middle reach, lower reach) and One Lake (Erhai Lake)'.

Due to the difficulty of sampling by both the local custom regarding fish as totem and atrocious environmental conditions, whatever fish species exist in the headwater of the Upper Mekong are still an enigma. Although the Mekong, the Yangtze and the Yellow River originate from the same district, comparing with the latter, only 8 fish species were recorded in the Upper Mekong in Qinghai province, equivalent to 40% and 25% of fish species in the Yangtze River and the Yellow River respectively (Wu, 1989).

Fish Biodiversity in the Lower Mekong

Only a small part of the Mekong flows through Myanmar, and therefore fisheries supporting the local food and economy mainly depend on the Irrawaddy River and the Salween River. Information on fishes of Mekong in Burma is unavailable. Only 2 species were recorded in MFD (Mekong Fish Database, MRC, 2003). A recent study on a China-Laos boundary river, the Nanla River, showed 42 species belonging to 4 orders, 14 families, and 34 genera. About 64.3% of the total number of species were Cypriniformes (Zheng et al., 2009). Hemibagrus wyckioides and Pangasius sanitwangsei are listed in the China Species Red List (Yue and Chen, 1998).

Based on MFD (MRC, 2003), 388 fishes of 155 genera and 55 families were recorded within the Mekong in Laos. It should be mentioned that some of these fish species are estuarine species. This suggests some fish species in the Mekong swim upstream over thousands of kilometers from the delta, while no evidence showed such long distance that diadromous fishes migrate in the Mekong. In a big tributary, Nam Ngum, 94 fishes were distributed, and in the Khone Fall, 93 fishes were sampled. According to Fishbase, 590 freshwater fish species are found in Laos (http://fish.mongabay.com/data/Laos.htm). Actually, water

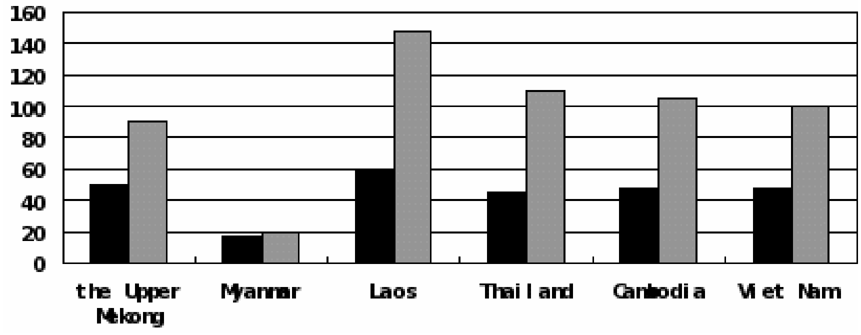

Figure 21.1: Fish composition of Cyprinidae in Mekong at different part. The black columns mean the genus number, and the gray ones mean the species number.

in Laos is mostly supported by the Mekong. This gap between the two results needs further revision.

According to MFD (MRC, 2003), 246 fish species belonging to 116 genera and 43 families were identified in the Mekong in Thailand. As Laos and Thailand lie on the opposing banks of Mekong's mainstream, the difference of fish species should be attributed to the species in Mekong tributaries in the two countries. Since tributaries of the Mekong in Laos contribute a large portion of Mekong mainstream water, Laos fish species could be more abundant than those of Thailand, even though a tributary in Thailand, Mun River, contains 134 fish species.

Different from other countries in Mekong basin, Cambodia regards Mekong fisheries of great importance to the local economy and as a food source. A totally of 282 species of 140 genera and 58 families were recorded (MRC, 2003). The Tonle Sap Lake, the largest freshwater fisheries basement in the world, contains 175 species. In the famous 3S river systems, 156, 128 and 126 fish species inhabit the Sekong, Srepok, and Sesan Rivers respectively.

There were 354 species of 134 genera and 77 families recorded in the Mekong in Viet Nam (MRC, 2003). In the big tributary Bassic River, 143 species were recorded. Many of these fish species are estuarine species mostly in the delta.

Cyprinidae is the most dominant family of all the fishes at each part of the Mekong. Except for lower numbers in Myanmar and higher numbers in Laos, there are about 45 genus of Cyprinidae in the Upper Mekong (figure. 21.1).

There was no significant difference in the order level between the Upper Mekong and the Lower Mekong, and the highest similarity was found between the middle and lower reach of the Upper Mekong at the

	Laos	Thailand	Cambodia	Viet Nam
Myanmar	0.242	0.240	0.231	0.208
Laos		0.667	0.726	0.672
Thailand			0.840	0.804
Cambodia				0.811

Table 21.1: Fish fauna similarity of countries in the Lower Mekong basin at genus level of Cyprinidae

genus level as 0.369 (Kang et al., 2009b). If only the genus Cyprinidae is considered, the similarity between Myanmar and Viet Nam was lowest at 0.208, and gradually increased along the decreasing distance to the estuary except for an exceptional value 0.840 between Thailand and Cambodia (table 21.1).
Similarity coefficient R was calculated by $R = \frac{c}{(a+b-c)}$, where c is the number of fish species found in both two areas, a is that in one area and b is in another (Chu and Chen, 1990).

Migratory Systems

It is clear, however, from both local knowledge and scientific investigations, a number of fish species appearing in the Mekong are migratory species. Fish migrations play an equally important role for fishing communities along the Mekong and the tributaries.

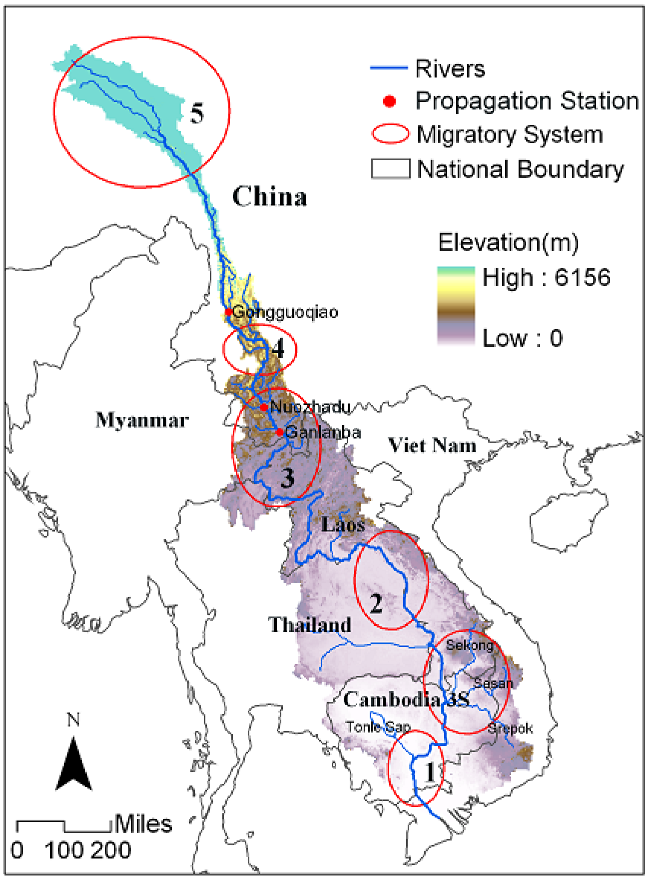

Figure 21.2: Fish Migration Systems in Mekong.

Many migratory stocks extend beyond national borders (often referred to as "trans-boundary" stocks). Though fishes never consider national borders as their barrier, many can finish their life cycle in a certain area. Three migratory systems (Poulsen et al., 2002), as well as a 3S (Sekong, Srepok, and Sesan) migratory system were found in the Lower Mekong Basin (figure 21.2). According to the systems, fishes accounted for the fisheries in Tonle Sap Lake, can successfully conduct their propagation and breeding in the system 1 and 2. Refined by the limited data, system 3 ended up to the national border between China

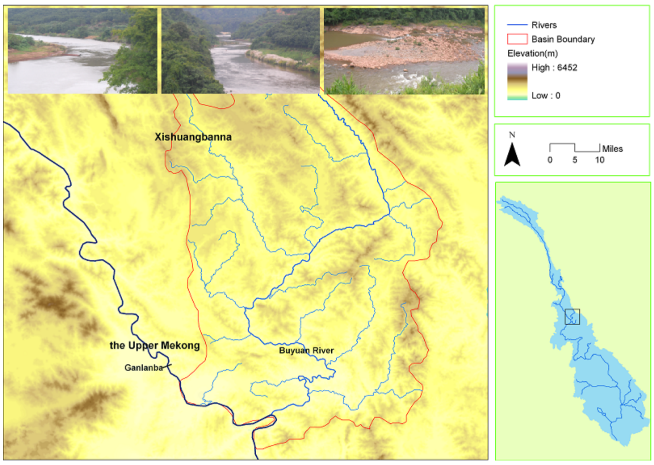

Figure 21.3: Sketch map of the Buyuan River basin of the Upper Mekong. The Buyuan River contains different kinds of aquatic habitats and spawning areas supporting a higher fish diversity.

and Laos. According to biological characteristics and fishers' knowledge, nearly 30 fishes show migratory action between the Chinese and Laos reaches of Mekong (Kang et al. 2006). Buyuan river (with suitable spawning habitats, figure 21.3) was certified as an important spawning area, and thus migratory system 3 can be said to extend to China's Ganlanba in Xishuanbanna. Moreover, in the Upper Mekong itself, there should be two more migratory systems based on the scientific sampling and local fishers' knowledge (Kang, 2009). System 4 located in Lincang, Puer, can be the migratory area for Platytropius sinensis (figure 21.4a), and system 5 in the headwater for Diptychus kaznakovi (figure 21.4b).

multiple stresses on fish biodiversity

Over-fishing has historically been considered as the most threats to Mekong fish and fisheries (Department of Fisheries, 1999). However, environmental degradation is increasingly becoming the major threat to biodiversity in rivers. Any spatial (e.g. habitat removal, river channelization, etc.) and temporal (e.g. hydrological regulation) simplification of the ecosystem will compromise the ecosystem structure and functioning, hence seriously threatening Mekong fishes. The interrelated

Figure 21.4: Migratory fishes in migratory systems 4 and 5. a: *Platytropius sinensis* b: *Diptychus kaznakovi*

impacts on local livelihoods and fisheries are key points of concern raised by inhabitants living along this stretch of the Mekong.

The main threats are mainly dam, navigation, climate change, irrigation, land erosion and pollution etc.

Dam Construction

Cascade dams can divide the mainstream into several huge reservoirs leading to fish habitat fragmentation (Nilsson et al., 2005). With an ever increasing population and energy consumption, the trend in Asia has been towards a greater number of large hydro-power dams being planned and constructed. Many dams exist in the tributaries, and plans on building huge cascade dams across the mainstream were, are and will be conducted. The completion of these dams is predicted to have great impacts on hydrology and the biotic conditions of the river downstream from the dams. Under scenario analysis, the seasonal regulation capacity of the Upper Mekong discharge will reach 100% with yearly regulation capacity at 23%, (He et al. 2007; Li and He 2008), and the hydrological regime will be significantly changed, with 94% of SSL (suspended sediment load) estimated to be trapped in reservoirs in China (Kummu and Varis 2007), as well as the spatio-temporal characters of water temperature (Yao et al. 2006).

Dams will obstruct the waterway connection, resulting in endangerment of fish species and the decline of fish recruitment dependent on migration. Fortunately, many species can finish in 1-2 systems, except four species of Pangasius (as Pangasius sanitwongsei, Pangasius nasutus, Pangasius beani, Pangasius micronemus, now revised into 3 species as Pangasius sanitwongsei, Pangasius djambal, Pangasius micronemus by Yang et al., 2007) that are regarded to migrate long-distances from Cambodia to Buyuan River in China (Yang et al., 2007). Moreover, the Irrawaddy dolphin could become locally extinct if a proposed dam is built on the Mekong River near the border between Laos and Cambodia, according to local environmentalists. There are also fears that the 240-megawatt Don Sahong dam (is planned for the Khone Falls in Laos), could interfere or even halt fish migration up the Mekong, with devastating implications for millions of people who are dependent on fish-based industries for their livelihoods (http://www.encyclopedia.com/doc/1G1-203026019.html). Cascade can also regulate the natural flow into Tonle Sap Lake (TSL). TSL is important in sustaining the health of fisheries of the Mekong as it is home to a large number of fish species.

Navigation

The "Mekong rapids blasting project", was originally conceived in 1992 by the Chinese government, in an attempt to improve the ability of commercial vessels to navigate from Yunnan province into Lao PDR, and Southeast Asia, along the Mekong. The project involves blasting (by explosives) and excavating a navigation channel through 21 rapids and shoals in the Mekong River along the Burma-Lao border, and the Thai-Lao border. The result would make the 361 kilometer section of the Mekong between Simao, in Southern China, and Luang Prabang, in northern Laos, much easier to navigate for large commercial ships (http://www.terraper.org/articles/Mekong%20Conference04Rapidsblast brief.pdf).

Although conclusions made by an Environmental Impact Assessment (EIA) report showed this project would not make long-term impacts on the fisheries and fishing-based livelihoods of communities living along the Mekong River in Laos and Thailand, this was doubted by many scientists (Cocklin and Hain, 2001; TERRA, 2003).

Normally, navigation would bring benefits as transporting the agricultural produce of remote farmers, reducing transport costs, giving better access to health care, education and water transport, as well

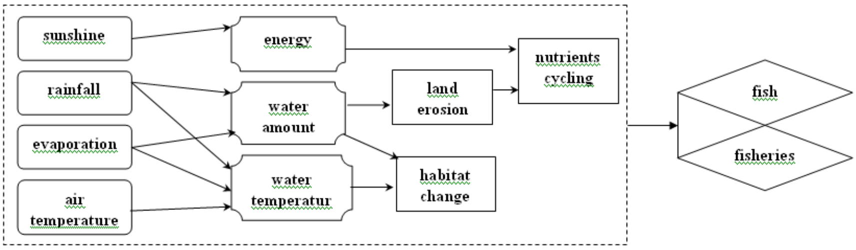

Figure 21.5: The sketch of impacts on fish biodiversity and fisheries by climate change

as increasing direct and trickle-down job opportunities. Meanwhile, navigation would also cause the destruction of ecosystems around the rapids and deep pools. According to the design plans for the navigation channel, the thousands of tons of rock blasted out of the rapids will be dumped in the deep pools of the river. The deep pools are critically important dry-season habitats for Mekong fishes. Filling the deep pools with the blasted rocks will have a severe and permanent impact on the fisheries.

Climate Change

The global discussion on climate change was until recently, focused mainly on its causes and impacts. In the Mekong basin, changes in weather patterns as a result of climate change are expected to cause a decrease in rainfall during the dry season and more rain in the wet season, with increasing variability across the region. This may lead to increasing seasonal water shortages, as well as higher frequency and increased severity of floods. Seasonal water shortages will increase the likelihood and severity of saltwater intrusion into the Mekong Delta.

Climate change will influence fish biodiversity and fisheries by changing the sunshine, air temperature, rainfall and evaporation, thus vary the river water volumes, water temperature, energy load, nutrient cycling, as well as the land erosion and habitat change, and nutrients cycling etc (figure 21.5). Changes in the flow of the river and tributaries could influence fish migration patterns.

Studies undertaken to date suggest a range of potentially significant impacts are possible by 2030 such as the increase in the mean temperature by 0.8°C and annual precipitation of approximately 13.5% across the whole basin. A change in rainfall patterns which could increase the risk of flooding in some areas and decrease precipitation in dry season in some areas, melting glaciers in the Mekong headwater will increase the contribution of snow melt to water in the river system, and increase salinity intrusion into the Mekong Delta (MRC, 2009). It is difficult to predict the coming impact of climate change for all the contradictory predictions by different scientists, but it is certain that climate change will have a significant impact.

COUNTERMEASURES

The conservation of fishes requires management of all the essential habitats upon which they depend, including the migration pathways between the habitats.

Many fish species in the Mekong are migratory and contributed 48% of the total fisheries (Poulsen et al. 2002), therefore conservation strategies must carefully consider the complex life cycles of migratory fish species and their ontogenetic shifts in habitat. Of particular concern, is that parent fish species will not be able to reach their spawning grounds as well as the fingerlings come back to the nursery habitats, under the increasing number of barriers created by dams in the Mekong Basin, potentially causing serious population loss (Baxter 1977; Craig 1992; Rosenberg et al. 1995).

It is expected that fishes with a high breeding ability, a short reproduction cycle and strong adaptability will obtain a new mode of reproduction, while fish with a longer reproductive cycle, low adaptability and low breeding ability will be greatly impacted from the environmental changes and may even become locally extinct if they can not adapt. Conventional fish ladders will not be successful for all migratory fishes, and fish passage can not mitigate the impacts by dams as flow regime change and habitat loss (Coutant and Whitney 2000; Schilt 2007). Even in the Mekong, ladders attached to such high dams are impossible.

The creation of specifically targeted protected areas is an important step in the conservation of the Mekong. Under the support of local governments and Huaneng Power International - China's largest independent power generator - which implements the Langcang water resource development, the Fish Conservation and Propagation Center (including natural conservation areas, propagation stations, staff training base) was set up at Nuozhadu, and another two are being planned for Gongguoqiao and Ganlanba (figure 21.2). Moreover, the cascade dams are being re-planned as the impending dam developments are being cancelled. In the Upper Mekong, Mengsong dam was cancelled

(Kang et al., 2006), and MRC cancelled a plan to build a 12-dam cascade across the Lower Mekong mainstream.

In additional, controlling the plan of excessive human economic activities such as mining and small dams, documenting and closely monitoring the fish species and developing effective conservation policies, are also advocated.

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22

COMMUNITY FISHERIES IN TONLE SAP, CAMBODIA

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ABSTRACT

This paper is concerned with poverty and livelihoods of fisheries communities in the Tonle Sap, particularly in areas located in Beoung Tonle Chhmar, a designated Protected Area "Bio-reserve". Both fishery resources and institutional contexts either enable or constrain the well-being of fishing communities. This paper demonstrates that the Tonle Sap Lake ecological system provides fishing resources, which sustain the livelihoods of a great number of people living around the Lake. The Tonle Sap Lake is not only important for local peoples' livelihoods, but it also generates 10% GNP to government's revenue, and much profits to private fishing lots.

Competition for fishing among different parties has increased over the years, resulting in the erosion of fishing resources. This, in addition to the growing scarcity of fish will directly impact on livelihoods and lower the well-being of the poor. This paper shows changes in the exchanges and mobility between two ecological regimes in which livelihoods and well-being of fisheries communities are likely to be affected negatively. People from outside the Lake area have migrated to the Lake for fishing. This has increased tension on the use, and further erosion of fishery resources. Livelihoods and well-being of local people in fisheries communities are therefore at jeopardy.

INTRODUCTION

Cambodia is located on the Gulf of Thailand and is bordered by Thailand, and Vietnam. The country covers an area of 181,035 km², spreading 450 km from north to south and 580 km from east to west. Two key physical features dominate the country: the Great Lake and the Mekong/Brassac/Tonle Sap river systems (DoF 2005). It is also located down stream (before Vietnam) of the Great Mekong Sub-region that includes Yunnan of China, Myanmar, Thailand, Lao PDR and Vietnam.

Only 3% of Cambodians are believed to have moved out of poverty between 1996 and 1999 (Murshid and Phim, 2005). About 36-39% of Cambodians continue to live below the national income poverty line, and more than four out of ten rural Cambodians are deemed poor. In addition, literature on the poverty and vulnerability in Cambodia, with special reference to the Tonle Sap region, suggests a poor linkage between macro-economic achievements and poverty reduction in the last decade.

Although there are many studies on poverty and livelihoods of rural people, especially focusing on communities based around the Tonle Sap, the poverty and well-being related to community fisheries in the Tonle Sap is a very challenging and critical issue for further study.

General feature of the Tonle Sap Great Lake

The lake was formed 5,000 – 6,000 years ago. It has a drainage area of about 67,000 km². The Tonle Sap Lake covers nearly 6% of Cambodia's total land during the monsoon. The lake drains through the Tonle Sap River towards the Mekong River in the dry season, contributing about 16% of the Mekong discharge during this season. At the beginning of the rainy season, the flow reverses as the Tonle Sap Lake is then filled by the Mekong due to the fast water level rise in the mainstream (Eric BARAN. 2005).

Dry Season: (Dec-May)

- 2,500 km² - 3,000 km² with an average depth of 0.8-1m
- 160 km long, 35 km wide,

Rainy Season: (May to October)

- 15,800km²
- 300 km long, 100 km wide, depth 10-14m (Baran, 2005).

The population is approximately 13.4 million in size, with a population density of 76 per km² (World Bank, 2005). About 85% of the population are farmers and mainly depend on natural resources and farming for their livelihoods (ADB, 2003).

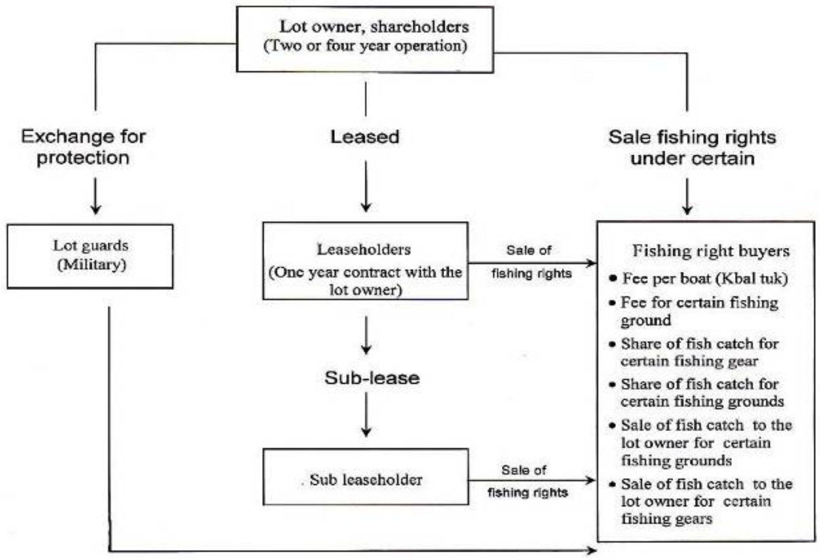

Figure 22.1: Fishing rights relations in the Tonle Sap Lake Communities

The Tonle Sap Lake Communities, Their Activities and Other Characteristics:

Fisheries have long been central to Cambodian lifestyles, particularly to communities living in and around Tonle Sap Lake. Fisheries from Tonle Sap areas contribute about 60% of Cambodia's total inland fisheries production (Baran, 2005), or between 200,000 to 218,000 tonnes based on average production from 2001-2003 (DoF, 2004), with landed values between US$150-250 million (MAFF-CNMC, 2003).

Fishing is generally categorized into three types: family fishing (or small-scale), middle-scale fishing and large-scale fishing (or fishing lot).

1. Family (or small-scale) fishing

   This is practiced by about every household around the Tonle Sap and is usually carried out by family members using small gears such as gill nets, bamboo fence traps. Family fishing does not require a license and it can take place all-year round. Considerable amount of catches are used for home consumption. Of all households actively involved in fishing, 90% are small-scale operators, (Vuthy et al, 1999)

2. Middle-Scale fishing

   This is for commercial purposes and is allowed only during October to May, when the water level in the Tonle Sap begins to recede and the floodplain area is decreasing in size. Under current regulations, a license is no longer required for middle-scale fishers. The gill nets are the main gears used by middle –scale fishers.

3. Large Scale fishing or fishing lot

   This is operated under a two-year lease system using gears that can cover large areas such as bamboo barrage traps and seine nets (Navy .H et al., 2006). Each fishing lot has a burdened book which guides the lot operator to follow the procedure and fishing operation guidelines in the burdened book. The burdened book highlights the operation period in the fishing lot areas and details the fishing gears to be used in each area defined in the fishing lots (FOA-DoF, 2003).

Dynamic of Development in the Beoung Tonle Chhmar

Under the Second Five Year Socio-Economic Development Plan 2002-2005 (SEDP 2), the Royal Government of Cambodia (RGC) committed to promote sound resource management practices and wise-use of natural resource as a foundation for balanced and sustainable development in Cambodia. Recently, government efforts to address the importance of wetland and wetland management have increased. This is especially true in regards to the Tonle Sap Lake and its ecosystems (Management Plan for BTC, 2002). Three areas have been designated as Ramsar Sites and Biosphere Reserve areas: Prek Tol, Boeung Tonle Chhmar (BTC) and Stung Sen River.

The designation of Boeung Tonle Chhmar (BTC) and others areas as either Ramsar sites and Biosphere Reserve core areas reflect the government's agreement to the three principles of the Ramsar Convention:

1. Maintaining the ecological character of the listed sites,
2. Making wise use of all wetlands, and
3. Establishing nature reserves in wetlands, whether or not they are included in the Ramsar list (Management Plan for BTC, 2002).

Boeung Chhmar Ramsar (BTC) was designated in 1999, covering an area of 28,000 ha (Mam et al., 2001). Unfortunately, the BTC has also been granted three commercial fishing lots (Lot No. 4, 5 and 6) that have been managed over the past regime. The Boeung Tonle Chhmar is rich in aquatic resources related to biodiversity, fish, provides a good habitat of various global threatened water bird species and several hundred of fish species which has much economic and conservation worth for Cambodia. Recently, those resources have declined and changed significantly due to many factors such as over-fishing, cleared flooded forest for agricultural expansion and lack of law enforcement. This has resulted in fish habitat destruction, declining fish yields, change in livelihoods of the local poor, and in-out migration.

COMMUNITIES IN BOEUNG TONLE CHHMAR

The geographical area of Boeung Tonle Chhmar is located in Peam Bang Commune, Stoang district, Kampong Thom province. The Peam Bang commune has five official registered villages which are namely Peam Bang, Pov Veuy, Doun Sdeung, Balot and Pich Chakrei villages.

Village Background

The villages are located in Peam Bang commune, and are floating residential villages, in which the residences move back and forth according to the seasonal fluctuations of the currents and water level. Villagers who live there have to adapt with nature, cope with unexpected situations and learn how to deal with changes in the natural phenomena. In general, during the rainy season period, villagers move their floating houses to settle nearby the flooded forest areas in order (22.2) to prevent risks from any natural disasters such as storms, unpredictable flooding and heavy rain-fall.

Within this period, villagers enjoy fishing and catching aquatic resources for their livelihoods and daily survival. Conversely, when the dry season starts, the water level of the lake goes down and flows into the Tonle Sap River which connects to the Mekong River and continues down to the Mekong Delta in Vietnam. This season, villagers have had to move back their houses out from the flooded forest to resettle in the open lake.

Among the six villages in the Peam Bang Commune, only two villages are selected for this case study. They are: Peam Bang and Pov Vouy villages. The villages are located within the boundary of Boeung Tonle Chhmar Biosphere Reserve and fishing lot concessions No.5 and No.6. Both village areas are flooded, therefore there is no rice growing. There is no clear data on land use because the surrounding area is flooded forest, which has been protected by law. During the dry season however, some households grow vegetables as “home-gardens” in small plots of land around their house.

Figure 22.2: Moving floating houses during flooding season: Photo by Sorphoarn, 2010

How Community Fisheries Establishments Respond and Contribute to Well-Being of Fishermen and Poverty Reduction?

A series of sub-decrees (anukrets) for each province were issued to formalize the release of fishing lots and setting up of community fisheries. For the rural population, particularly those around the Tonle Sap, the fact that these fisheries policy reforms were announced by the highest political leader was a matter of great significance. In February 2001, Cambodia became the first country in Asia to set up a separate Community Fisheries Development Office (CFDO) within the Department of Fisheries and encouraged them to undertake more participatory management of the floodplain fisheries in the country (Kurien, J et al., 2006).

To respond and make efforts to improve well-being and poverty alleviation of fishery communities and local people, the government, especially, the Fishery Administration has initiated and committed to the establishment of Community Fisheries (CFs) which began in 1999, and followed the abolishment of several fishing lots in Tonle Sap Lake. Over 360 fishery communities exist across the whole country. The fishery community is confined to small scale-fishing only. The degree of organization of these fishery communities varies greatly, with

Province	No of Fishery Communities
Siem Reap	10
Kompong Thom	10
Battambang	18
Pursat	14
Kompong Chhnang	44
Total =	96

Table 22.1: The Number of Fishery Communities in the Tonle Sap Lake
Source: Provincial DOF officials, 2003

some having almost no substance or structure other than a name, to more comprehensive interventions such as those supported by the FAO Participatory Natural Resource management project. Only 13% of these fishery communities have rules and regulations, 6% have an actual map of their boundaries. Importantly, only 5% have been legitimately recognized at the Provincial level and none can be recognized under the country's law (ADB, FAO &DoF, 2003).

To give reform measures the necessary legal standing, a sub-degree on fishery communities was prepared, and was publicly discussed in each province. The final draft was then formulated and passed on to the Ministry of Agriculture, Forestry and Fisheries (MAFF) for submission and approval by the Council Ministers. Together with the sub-decree on community fisheries, the more important fishery law, intended to replace the existing Fishery Law of 1987, was also submitted to the Parliament in early 2004. The new Fishery Law will provide the legislative framework for the new management structure for fishery communities. A Royal Decree on the establishment of Community Fisheries was proclaimed and The Sub-Decree on Community Fisheries Management (SDCFM) was issued in June 2005.

In early 2002, two fishery communities were established in which initiative and support by the Department of Fisheries came through the SangKat Nesat which is based in the Peam Bang commune: Peam Bang and Pov Veuy villages. However, in 2005, another fishery community initiative was established in the Don Sdeung Village even though these fishery communities have not been well structured nor are well functioning, and have unclear boundary demarcation.

The key goal of the fisheries reform policy is to enforced measures to eliminate tensions and conflict over fishery resources between the local people who depend on fish protein for their survival, with commercial fishing lot owners. Beyond that, the fishery reform policy aims at strengthening and improving local livelihoods, sustainable fishery resources and poverty eradication through encouraging local people to establish fishery communities. Field surveys have shown that many forthcoming and weakness points were found:

- Most of the fishermen do not fully understand fisheries reform policy yet.
- Fisherman who are better off tend to have more capital inputs like modern boats, fishing gears and labor, and are therefore better able to access more fish resources than the poor fishermen, who have less inputs to access fish resources and tend to remain poor and impoverished.
- Poor fishermen tend to borrow money from private money lenders at very high interest rates in order to purchase equipments such as machines and fishing gear to catch more fish, as well as food consumption. Under the borrowing agreement, fishermen are often required to sell their catch to moneylenders at a set market price.
- At the opening of the fishing season, fish yield prices are very cheap. Sometimes poor fishermen are able to catch only small amounts of fish, which gradually makes them poorer and they fall into a debt trap, requiring some families to repay their debts from one generation to the next.
- There is no clear boundary demarcation of public fishing ground and allocated areas; sometimes allocated areas cover paddy fields which have no fish resources.
- The fishery community is a priority solution for sharing resources to the poor, but most of them do not even know the meaning of community. This is why they become more confused of the meaning of the fisheries reform policy. As results have shown, the poor often receive no benefits from the policy.
- The policy provides benefits only to a small amount of people: those who have opportunities to access fishery resources,

especially the rich and powerful. As such, the government's rectangular strategy has not yet contributed to poverty reduction .

- Conflicting resource use among stakeholders: because of its rich fish biodiversity and availability of fertile soil, the Boeng Tonle Chhmar lake attracts many people from upland Kampong Thom and Siem Reap provinces, as well as Pursat and Kampong Chhnang provinces. They tend to set up permanent settlements in the area or work as seasonal fishers. There does not seem to exist an institutional framework or other mechanisms that regulates competition for resources between original and new settlers, or resident and migrant fishers. As mentioned above, the lake comprises of three commercial fishing lots that require a great number of workers to run the lots during fishing season. These workers stay in the area permanently, and together with the new settlers, have made an impact on the natural resources in the area (Mam et al., 2001).

How local villagers involve in fisher Community and its implementation:

Fishery communities have limited rights. This includes the right to protect the area from illegal fishing (ie. direct enforcement) and the right to harvest fish on a large scale to raise funds for the community. The rights of the fishery community Organizations to enforce rules, suppress illegal activity, and generate income should be clarified. The community fisheries have been established from top-down, with weak local supports, making communities struggle with illegal fishing operators and corrupted officials. The Sub-decree on Fishery Community has been drafted in favor of Department of Fisheries, promoting centralized management of community fisheries and several consultations were carried out and several drafts (more than 10 drafts) of Sub-decree has been released but still poorly integrated civil society and community comments.

Some people have questioned that the fishing grounds which have been released, are not resources full areas. Some places have no water in the dry season and some places the water level is too deep that poor fisherman could not be able to access to those areas. So fishing areas that most of people can access is still small that cannot support to the currently population in addition with seasonal-internal migrant. As a result with this problem usually the conflicts among people have been occurred (Case study of RUPP's students, 2005).

CONCLUSION

The paper notes that fisheries are still of great importance for Cambodia, especially people around the Tonle Sap Lake in terms of food security and well-being. With rich in aquatic resources, ecological diversity, landscape patterns the Tonle Sap Lake, has contributed a lot in terms of world heritage values (Bio reserve), food security, livelihoods and revenues to national treasure are and have been recognized nationally, regionally and globally. Current pressures of dynamic globalization, rapidly economic development, changes, have direct and indirect shaped and changed partially to the lake and livelihood of local people who mainly depend upon resources in the lake as result in fisheries yield has remarkably declined, ecological changed and hydraulic changed.

These impacted on the living condition of villagers, are still poor, their income generation is very low and to be survival and adaptable to those, some fishermen tried to borrow money to catch fish, but finally, they get indebts which they can not repay until next generation. However, to response and efforts, fisheries reform policy to release fishing lot areas to public fishing ground, communities fisheries establishments have applied and implicated in the Tonle Sap lake, particularly, three community fisheries were established in the study areas (two villages), to response and meet the needs of local people, especially poor fishermen, but until now these communities fisheries seem to be not yet well functioning and structuring in sense of management, roles and responsibility and participation from local fishermen. The human resources and capacity building of CF committees are needed to improve, inadequate resource materials for running activities. The structure of CF committees is not knowledgeable, recognizable and committable to protect fisheries resources as they are still poor and their living conditions require them to take responsible for family living and income earning.

Unclear demarcation of boundary of areas of CF is which result in having some difficulties to recognize and deal with where is boundary of CF and fishing lot to manage and control. by observations, the poor become poorer as they have no any capital investment, are using out-off-date fishing gears as if it put to the compare to some better off families who have more inputs then they are able to use modern boats, fishing gears to catch huge amount of fish. Besides, long life fishing occupations of fishermen, some poorer fishermen shown and expressed that they started to give up their fishing practice to migrate to city or town seeking for jobs and income that they are no any professional or skill and uneducated people and at risk with black market works, especially young generation.

Remarkably, at the moment, a few local and international non government organizations have supported technical advises on communities fisheries establishment, training on human rights to local authorities and provincial department of environment constructed a building of ranger station in Pov Vouy village to patrol any illegal activities, which funded by ADB. Moreover, there are many donors invest in loans or small grant for development and improvement the Tonle Sap lake and including policy reform, sub-decrees, regulation are aiming to poverty alleviation, improve local livelihoods, well-being increasing and sustainable and maintainable ecological biodiversity and fisheries resources, but as the study result findings at the villagers in Peam Bang commune, indicated that, at the moment, the both villagers, especially poor fishermen, communities show that their livelihoods, well-being are still miserable and impoverish.

In conclusion, livelihoods and well-being of communities in Tonle Sap lake, especially, in Beoung Tonle Chhmar is very important and significant to be taken into consideration. The efforts and achievements and communities fisheries establishments are tools and strategies to poverty alleviation, sustainable use of resources and improve local livelihoods and well-being, but those needs to come along with reinforcement of policy reform, complied with laws and participation from all stockholders, especially local people in order to achieve its efforts and mutual achievement. The communities' fisheries would be strengthened and encouraged local people to full participating in the process of setting up in order that they will learn and understand how they are important for their livelihoods and value of resources.

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