



FRESHWATER under THREAT SOUTH EAST ASIA

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Vulnerability Assessment of Freshwater Resources to Environmental Change

The South East Asia is endowed with abundant water resources. The average annual per capita water resources in the region is almost double the world average. Nevertheless, the region's major river basins are under considerable pressure from rising human numbers and economic activities. Lack of access to water resources remains a challenge to the livelihoods of a great majority of the populations in many basins (especially those at the subsistence level). Its largest river, the Mekong, has withstood decades of pressure from rising human numbers, growing industrial activity and more demands for water and food for over 65 million people. Large-scale infrastructure development and alterations of the natural water regime have provoked ecological concerns. Cambodia's Tonle Sap (Great Lake), the nursery of the lower Mekong's fish stocks, and Vietnam's Mekong Delta, its "rice bowl," are particularly at risk from alterations in the Mekong River's unique cycle of flood and drought. Adding to challenges two out of every five people lack safe drinking water supply and proper sanitation. Climate change could aggravate the vulnerable water situation in the coming years and decades. All these imply that expanding and strengthening the links between the technical and political processes at work within all co-riparian will play vital roles to reduce water vulnerability in the future.



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FRESHWATER under THREAT SOUTH EAST ASIA

Vulnerability Assessment of Freshwater Resources to Environmental Change
Mekong River Basin

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This report also utilizes data and information published by many other organizations. These sources are specified where appropriate in the text, as well as listed in the References.

Acronyms

ADB	Asian Development Bank
AIT	Asian Institute of Technology
AQUASTAT	FAO Information System for Water and Agriculture
CV	Coefficient of variation
CRU	Climate Research Unit, University of East Anglia
DP	Development pressures
EH	Ecological health
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIS	Geographic Information System
GMS	Greater Mekong Sub-region
HDI	Human Development Index
IWMI	International Water Management Institute
Lao PDR	Lao People's Democratic Republic
LMRB	Lower Mekong River Basin
MC	Management challenges
MDG	Millennium Development Goals
MRB	Mekong River Basin
MRC	Mekong River Commission
OSU	Oregon State University
PPP	Purchasing power parity
PRC	People's Republic of China
RS	Resource stresses
SE	South East
UMRB	Upper Mekong River Basin
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UN-Habitat	UN Human Settlements Programme
US	United States
VI	Vulnerability Index
VNMC	Vietnam National Mekong Committee
WB	World Bank
WRI	World Resources Institute
WUP	Water Utilization Programme of MRC

Abbreviations and Symbols

BCM	Billion cubic metre
cap.	Capita
DDT	Dichloro-diphenyl-trichloroethane
km	Kilometre
km ²	Square kilometre
km ³	Cubic kilometre
masl	Metre above sea level
MCM	Million cubic metre
MW	Megawatt
m ³	Cubic metre
PCB	Polychlorinated biphenyl
Pop.	Population
Yr	Year
S	Second
m ³ .s ⁻¹	Cubic metre per second

Table of Contents

Acknowledgements	IV
Acronyms	V
Abbreviations and Symbols	V
Tables, Figures and Boxes	VII
Foreword	IX
Executive Summary	X
1. Introduction	1
1.1 Rationale	1
1.2 The Assessment Process	1
1.3 Scope and Limitations	2
1.4 Structure of the Report	2
2. Methodology	3
2.1 Approach	3
2.2 Diagnosis of Issues	4
2.3 DPSIR Analysis	4
2.4 Vulnerability Index and Parameterization	4
3. Overview of Freshwater Resources of South East Asia	7
3.1 Geography and Socioeconomics	7
3.2 State of Freshwater Resources	9
3.3 Main River Basins in South East Asia	10
3.4 Description of the Selected River Basin: The Mekong	10
4. Vulnerability Assessment	17
4.1 Resource Stresses	17
4.2 Development Pressures	18
4.3 Ecological Insecurities	19
4.4 Management Challenges	21
4.5 Vulnerability Index	22
5. Conclusions and Recommendations	23
References	27
Glossary	29

Tables, Figures and Boxes

List of Tables

Table 2.1 Conflict management capacity parameter assessment matrix	6
Table 2.2 Interpretation of Vulnerability Index	6
Table 3.1 Geography and population dynamics of South East Asia	8
Table 3.2 Land use patterns, GDP, HDI and Gini Index of South East Asia	8
Table 3.3 State of freshwater resources in South East Asia	9
Table 3.4 Access to improved source of drinking water and sanitation in South East Asia	9
Table 3.5 Major river basins in South East Asia	10
Table 3.6 Water resources in the Mekong River Basin	11
Table 4.1 Sources of freshwater vulnerability in the Mekong River Sub-basins	22

List of Figures

Figure 2.1 Freshwater resources vulnerability components and indicators	4
Figure 3.1 South East Asia	7
Figure 3.2 Major river basins of South East Asia	11
Figure 3.3 The Mekong River Basin	12
Figure 4.1 Coefficient of variation of precipitation in December in the Mekong River Basin	17
Figure 4.2 Annual water exploitation in the Mekong River sub-basins	18
Figure 4.3 Population without access to safe drinking water in the Mekong River sub-basins	18
Figure 4.4 Land area without vegetation in the Mekong River sub-basins	19
Figure 4.5 Population without access to improved sanitation facilities in the Mekong River sub-basins	19

List of Boxes

Box 3.1 Flooding in Tonle Sap, Cambodia	13
Box 3.2 Risks posed by construction of hydropower dams in the MRB	13



1	3
2	4

1. Early morning at Thung Salaeng Luang National Park, Phitsanulok, Thailand

Source: Nadhika Mendhaka

2. Young girl drinking water, Thailand

Source: Nadhika Mendhaka

3. A kid drawing water from storage tanks in Kanchanaburi, Thailand

Source: Kin Mar Cho

4. Khao Laem Dam Reservoir, Sangklaburi, Thailand

Source: Theerachai Haitook



FOREWORD

Freshwater resources – essential for life on Earth and the achievement of the Millennium Development Goals (MDGs) – are increasingly vulnerable. A reliable assessment of the current status of major river basins is needed. Major constraints to such an assessment have been a widespread lack of operational frameworks and the availability of accurate and timely data at the basin, and more significantly, sub-basin scale. However, progress in our understanding of vulnerability, and in data gathering and processing techniques offer promising avenues to overcome these challenges.

The United Nations Environment Programme (UNEP) has joined hands with a number of regional partners from Africa and Asia to address the issue of vulnerability of freshwater resources in the major basins in these continents. The Assessment of Freshwater Resources Vulnerability of South East Asia, produced through collaboration between UNEP and the Asian Institute of Technology (AIT), Thailand, is one of a series of reports, which has been the outcome of this partnership.

More than 15 transboundary river basins of various scales in terms of drainage area and water resources are situated in South East Asia. The Mekong River Basin, largest in South East Asia, was chosen for an in-depth vulnerability assessment at a sub-basin scale. The Mekong River, and its tributaries which form the vast Mekong River Basin, drain a total catchment area of 795,000 km² within China (Yunnan Province), Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam. A composite Water Vulnerability Index – estimated based on analysis of water resources stresses, development pressures, ecological insecurities and management challenges – indicates that water resources in the Mekong River Basin are moderately vulnerable. Although the river basin is not characterized by either water shortage or open conflicts, the basin is still exposed to potential threats posed by development pressure and transboundary issues. Development pressure emanates from the unsustainable exploitation of water resources during the dry season in parts of the basin, and inhabitants' lack of access to safe drinking water in other parts.

The contrasting scenario of abundant water availability and lack of water service provision in the Mekong River Basin calls for a balance between resource exploitation and maintenance of ecological health. There is an urgent need to reach consensus on equitable water utilization and management among co-riparian countries by consolidating ongoing cooperation. In this context, it is our hope that this first assessment should initiate a long-term process of periodic review and update to give an authoritative picture of water-related vulnerability, and provide the empirical basis for integrated and sustainable river basin development.

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Executive Summary

The river basins of South East Asia have been the subject of a number of studies shedding light on the complexity of their natural, political, social and economic issues. Although the diversity of these studies and reports serves as a knowledge base for the basins, one can rarely find a study that provides a holistic view of the water-related vulnerabilities in the basins. This report is one of the outputs of the Vulnerability Assessment of Freshwater Resources to Environmental Change project, presenting a situation analysis with regard to the vulnerability of water resources system in South East Asia. In addition to the more general South East Asian water issues addressed herein, the report considers Mekong River Basin in detail as a case study. Though the Mekong River Basin (MRB) is currently not characterized by either water shortages or open conflicts, it warrants attention due to the potential future threats that might arise from development pressures and transboundary issues.

Methodologically, this study focuses on isolating strategically-important issues related to different functions (uses) of the water resources in the MRB and its sub-basins, thereby marking a considerable departure from the preconceived notion of “water crisis” being synonymously linked to water vulnerability. Based on the premise that a vulnerability assessment of the river basin must be based on the precise understanding of total water resources availability, development and use, ecological health and management, including their states and interactions, nine vulnerability parameters are identified. Evaluation of these parameters are done on the basis of the current state-of-the-art in vulnerability assessment and a number of constraints related to data and information, including lack of access to some official data, and wide seasonal and spatial variations in the hydrology of the MRB and its sub-basins. A composite vulnerability index (VI) is calculated on the basis of four dimensions of water vulnerability: resources stresses, development pressures, ecological insecurities, and management challenges. Analysis at sub-basin scale distinguishes this report from other similar reports.

Despite population pressure (with the region’s population density being 2.6 times that of the world average), the annual per capita water resources availability exceeds 5,800 m³ in all South East Asian countries, except Singapore. The average annual per capita water resources of 12,980 m³ in the South East Asian region is almost double the world average. The total water withdrawal is 4.5 per cent of the available water resources, although variations exist among the countries, ranging from 0.9 per cent in Cambodia and Lao PDR, to 21.2 per cent in Thailand. The agricultural sector is the major water consumer (85.5 per cent of total water use), followed by the



industrial (7.8 per cent) and domestic sectors (6.6 per cent). The productivity of water use, measured as GDP produced per cubic metre of water use, ranges from 0.5 US\$/m³ in Viet Nam, to 10.5 US\$/m³ in Malaysia. The region's rapidly industrializing and urbanizing countries (Malaysia; Philippines; Indonesia; Thailand) have relatively higher water productivity, reflecting the higher value of water in the industrial sector. Inhabitant's access to safe drinking water and improved sanitation facilities in the South East Asia (except Cambodia and Lao PDR) are high, compared to the world average.

In-depth analysis of the Mekong River Basin reveals massive variations in seasonal water availability, with the wet season (May to October) surface water availability accounting for about 85 per cent of the annual total volume of about 460,000 million m³. Sub-basins in Lao PDR contribute the highest water volumes (about 162,000 million m³. year⁻¹) to the MRB, accounting for about 35 per cent of the annual total volume. Although the basin-wide annual per capita water resources availability exceeds 7,000 m³, the annual per capita water availability in the Mun Chi sub-basin of the lower MRB (about 1,800 m³) is close to water stressed condition (1,700 m³.capita⁻¹.year⁻¹) proposed by Falkenmark and Widstrand (1992).

The co-riparian countries of the MRB are heavily dependent on the freshwater from the Mekong and its tributaries. People and environment in 97 per cent of the land area of Lao PDR, 86 per cent of Cambodia, and large areas of Thailand and Viet Nam, meet their water needs from the Mekong River Basin. Yet, rich endowment of water in the MRB means that annually, less than 15 per cent of the available water resources are exploited. Only Mun Chi sub-basin of Thailand, and Mekong

1 Golden Triangle, Mekong River, Thailand

Source: *Nadhika Mendhaka*

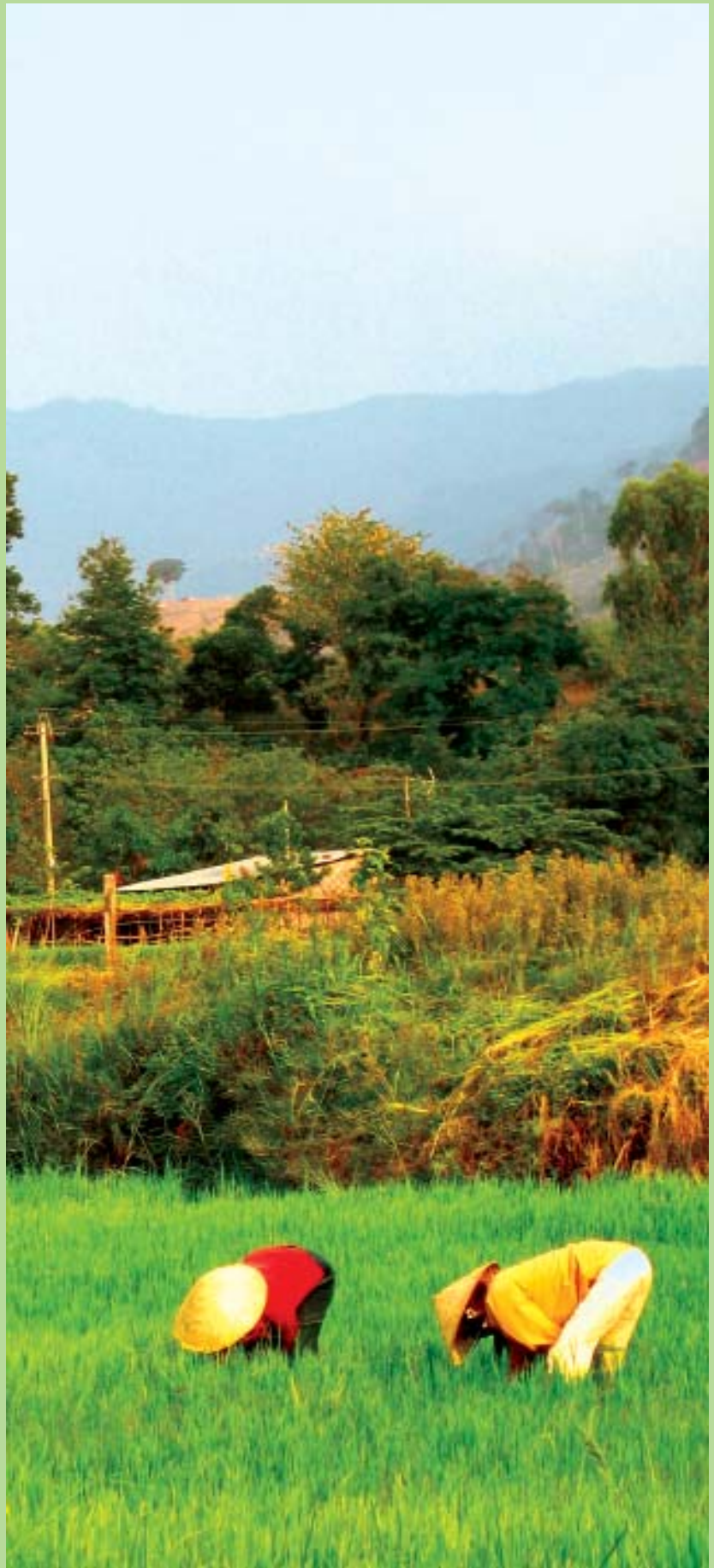
2 A fisherman on a boat on Mekong River, Viet Nam

Source: *www.sxc.hu/ Paul Lensen*

3 Poor mother and son, Laos

Source: *Nadhika Mendhaka*

“Though the Mekong River Basin (MRB) is not characterized by either water shortages or open conflicts, it warrants attention due to potential threats that might arise from development pressures and transboundary issues.”



Farmers weeding ricefields, Viet Nam
Source: Nadhika Mendhaka

Delta and Sekong-Sesan-Srepok sub-basins of Cambodia and Viet Nam use more than 40 per cent of the available surface water during the dry season.

Water pollution generally has not reached an alarming level in the basin, except in the Mekong Delta. This situation corresponds to the absence of major population and industrial centres (except Phnom Penh) along the river. Even intensive agriculture is limited to parts of the Mun Chi sub-basin in Thailand, and areas of the Mekong Delta in Viet Nam.

Despite an abundant availability of water, and low levels of exploitation and pollution, the MRB may still face challenges due to lack of technical support and management capacity. More than 50 per cent of sub-basin population in six MRB sub-basins (representing 20 per cent of the total MRB population) lack access to safe drinking water. The situation is distinctly better (20 per cent of the population lacks access to safe drinking water) in sub-basins predominantly within Thailand. People's access to improved sanitation facilities in the MRB varies between 41-72 per cent of sub-basin population in Lao PDR, Cambodia and Viet Nam. The largest number of people lacking access to improved sanitation facilities (72 per cent) is in the Nam San sub-basin in Lao PDR. The GDP produced from one cubic meter water use is US\$ 2.4 in the MRB which is far less than the US\$ 23.8.m⁻³ GDP generated by the top five food producers in the world (China; USA; Mexico; Brazil; France).

The overall Vulnerability Index of the MRB is 0.31, which means that the basin is moderately vulnerable to environmental changes. Tonle Sap, Nam Khan and Sekong-Sesan-Srepok are the most vulnerable MRB sub-basins. Vulnerability is largely related to lack of capacity of the co-riparian countries to manage the water resources in the face of development pressures.

Given the contrasting scenarios of rich water availability (in volumetric terms) and lack of water service provisions, the challenges facing future policy formulation to reduce water-related vulnerability encompasses achieving a balance between resources exploitation and maintenance of ecological health. Thus, resources exploitation through infrastructure development should be envisaged with caution. The second key direction regarding water management of the Mekong River Basin is to acknowledge the need to reach consensus on equitable water utilization between the upstream and downstream co-riparian countries (including provision for the environment). Considering the high economic growth rates in the MRB, and the consequent need to harness its water resources, the consolidation of ongoing cooperation among the co-riparian countries will be the cornerstone of any sustainable approach to reduce the MRB's water vulnerability.

To prepare for the water-related impacts of climate change and sea level rise in South East Asia, there also is a need to expand and strengthen the climate change knowledge base, and promote education and awareness raising in the region.

It is anticipated that the computed Vulnerability Indices of the sub-basins will guide decision-makers and planners to focus policies towards addressing issues of more vulnerable sub-basins. The comprehensive and easily interpretable findings will help reach sound solutions to the rising concerns about development of the basins in Asia, and to devise cooperative plans among the basin countries.

1

Introduction

1.1 Rationale

Asia's underdeveloped condition has increased the sensitivity of its communities to biophysical, socioeconomic or geopolitical changes. They can affect the ability of water resources systems to function effectively and efficiently, thereby making it vulnerable in terms of quantity (overexploitation, depletion etc.) and quality (pollution, ecological degradation etc.). Understanding the vulnerability of water systems in Asia is, therefore, vital to sustainable water resources management in Asia. The United Nations Environment Programme (UNEP) and the Asian Institute of Technology (AIT) undertook a study to address the issue of vulnerability of freshwater resources in Asia. The objectives are closely related to the commitment of the international community to implement integrated water resources management. Thus, the focus is to assess the vulnerability of freshwater at river basin and sub-basin scales. The specific objectives of the assessment are:

- To develop knowledge and understanding necessary for forward-looking cooperation among riparian states with regard to competing water demands;
- To examine water issues and functions in selected river basins;
- To evaluate impacts of environmental change in terms of water resource stresses and management challenges; and
- To complement the efforts and activities of governments, non-governmental organizations (NGOs), and development agencies engaged in improving the status of water systems, by providing facts, figures and analyses related to water resources vulnerability.

This assessment focuses on four river basins in Asia; namely, Ganges-Brahmaputra-Meghna (GBM), Indus and Helmand in South Asia; and Mekong in South East Asia. These four basins mainly comprise developing countries in which the available water resources strongly influence the economic and social development of the countries. This report provides a freshwater resources vulnerability assessment of South East Asia, based on the analysis of the Mekong River Basin (MRB), a transboundary river basin covering China, Myanmar, Lao PDR, Cambodia, Thailand and Viet Nam.

1.2 The Assessment Process

The river basin vulnerability assessment followed the Methodological Guidelines developed by UNEP and Peking University (PKU). First, a desk study involving intensive review of relevant research papers, policy reports, maps etc. is conducted. This led to the formulation of a conceptual framework of analysis and detailed work plan. Second, the state and characteristics of the water resources of the study river basins and their management systems were analyzed to identify the key issues influencing the vulnerability of water resources. This information served as the basis for the in-depth DPSIR (Drivers, Pressures, State, Impacts and Responses) analysis and a qualitative and quantitative description of the vulnerability of the water resources of a river basin. Third, a composite Vulnerability Index (VI) is calculated based on a number of vulnerability indicators.

Consultation Process

To ensure the correctness of data and information, and the validity of the assessment, experts comprising representatives from governments, academia, and the private sector, reviewed the reports. A peer-review workshop was held in September 2007 with participation of the water experts from Afghanistan, Bangladesh, India, Iran, Nepal and Pakistan from South Asia; Cambodia, Laos, Thailand and Viet Nam from South East Asia; and China and Mongolia. The workshop identified the strengths and weaknesses of the draft reports, as well as provided recommendations and additional data for improving and updating relevant information contained in the draft reports. Based on the comments of the experts, the reports were appropriately revised to incorporate the updated and additional data and information provided through the review process.

Summary for Decision Makers (SDM)

The Summary for Decision Makers (SDM), published as a separate report by the UNEP, synthesizes the key findings, gaps and challenges based on the assessment, in the form of main messages. The SDM highlights new insights into the vulnerability of the freshwater resources systems in nine major river basins of North East, South and South East Asia, and provides critical points of reference to identify policies and recommendations for reducing water resources vulnerability.

1.3 Scope and Limitations

For in-depth vulnerability assessment of freshwater resources in South East Asia, only the Mekong River Basin (MRB) was considered, based on its hydrologic and physiographic characteristics and important socio-environmental functions. To account for spatial variations in water availability, development, use and management capacity within the river basin, 23 sub-basins were considered. Unlike traditional assessments,



however, this study relies to some degree on informed estimates, which were validated with recourse and views of additional informed experts and published documents including internet web resources. As such, strict numerical validity was not considered the core issue. Rather, the directions of causality related to vulnerability outcomes were emphasized. Nevertheless, this assessment is not a substitute for a rigorous quantitative analysis, but rather is intended to complement such a comprehensive study. Thus, this assessment should be regarded as the first edition of future comprehensive analyses at river basin or local level.

1.4 Structure of the Report

This report is divided into five chapters. The first chapter introduces the study, answering two major questions: Why vulnerability assessment is important? How is the vulnerability assessed? The second chapter summarizes the specific methodology used in the assessment including calculating the composite Vulnerability Index (VI). The third chapter describes the important geographic and socioeconomic conditions of South East Asia. It also outlines the status of the region's freshwater attributes, and provides background for in-depth analysis of water vulnerability of the Mekong River Basin. The chapter also presents the climate change effects on the water resources of the basin. The fourth chapter contains the findings of the vulnerability assessment for the Mekong River Basin. The objective is to examine the significance and magnitude of environmental and socioeconomic factors associated with freshwater resources vulnerability. The fifth chapter provides the conclusions of the assessment, based on the relevant findings presented in the previous chapters. General policy directions aimed at minimizing the vulnerability of freshwater are suggested.

1. Kids from Laos
Source: www.sxc.hu/ David Lahav
2. Vietnamese Woman
Source: Nadhika Mendhaka
3. Kids in Sangklaburi, Thailand
Source: Anastasia Yunika

4. Kongmongtha Villager, Thailand
Source: Michael Zoebisch

2

Methodology

2.1 Approach

The method used for this vulnerability assessment, based on the Methodological Guidelines prepared by UNEP and Peking University (UNEP-PKU, 2009), is briefly discussed in this chapter. The vulnerability of freshwater resources was explored by isolating strategically-important issues related to different functions (uses) of freshwater systems in a drainage basin, marking a considerable departure from the preconceived notion of “water crisis” being synonymously linked to vulnerability. Thus, this analysis is based on the premise that the vulnerability assessment of a river basin must have a precise understanding of four components of water resources system, including their states and relationships, as follows:

- **Total water resources:** Analysis of the hydrologic balance, prior to consideration of any water resources development and use; mainly comprising the water resources formulation from a natural hydrologic process, and its relationship with global climate change and local biophysical conditions;
- **Water resources development and use:** Analysis of water resources supply and balance, mainly the water resources development capacity available via an engineering approach and its relation to water resources use and development trends, and with the process of urbanization, as well as water resources support to the economic development;
- **Ecological health:** Analysis of water resources, after development and use for human and economic use, to be utilized for maintaining the basin’s ecological health, and the supply and demand relations, and key issues in the process. At the same time, the analysis needs to be conducted on water quality, as a consequence of water resources development and use (pollution), and its further influences on the freshwater resources budgeting within a river basin;
- **Management:** The above three components focus on the natural processes or natural adaptation of freshwater resources development and use. However, the natural processes are usually heavily influenced by the capacity to manage freshwater resources; that is, the management capacity plays an important role in sustainable development and use of water resources. Thus, the assessment is expanded to include evaluation of the state of institutional arrangements and other factors in freshwater resources management.

This assessment approach recognizes that a sustainable freshwater system can only function within an integrative operational framework that combines both the natural system and the management system. The fundamental components of current vulnerability assessment are able to account for three different aspects related to the natural resource base, and how other factors (climate change, biophysical conditions, policy and management practices etc.) influence the processes that make a natural system vulnerable. Evaluation of the different components is based on the related indicators (Figure 2.1), considering a number of constraints related to data and information, including lack of access to some official data, and wide seasonal and spatial variations in the basin hydrology.

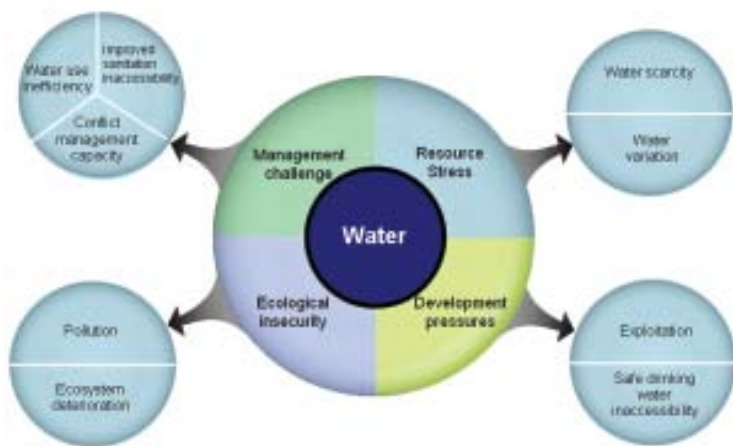


Figure 2.1 | Freshwater resources vulnerability components and indicators

The core method builds on a two-step exercise: (1) diagnosis of issues; and (2) in-depth assessment of the identified issues, using a DPSIR framework. A comprehensive vulnerability analysis was subsequently carried out, following a composite Vulnerability Index (VI) calculation based on four components of water vulnerability; (i) resource stresses; (ii) development pressures; (iii) ecological insecurities; and (iv) management challenges.

2.2 Diagnosis of Issues

To better understand the water resources vulnerability of river basins, basic data were collected from different sources regarding their current state and development, in terms of the water resources base, and its use and management. The output of this exercise was a detailed description of the water resources functions and key issues.

2.3 DPSIR Analysis

The analytical framework, known as Drivers, Pressures, State, Impacts and Responses (DPSIR) framework, used by the UNEP GEO process and others, was employed to put the vulnerability assessment into perspective. It integrates both anthropogenic as well as environmental change (caused by human activities and natural processes) factors, and incorporates social, economic, institutional and ecosystem pressures.

The DPSIR analysis was carried out for each identified issue. The Driving forces (D) represent major social, demographic and economic developments, and corresponding changes in lifestyles, and overall consumption levels and production patterns. Demographic development may be regarded as a primary driving force, whose effects are translated through related land use changes, urbanization, and industry and agricultural

developments. The pressures (P) are subsequently developed as an effect of these driving forces. The pressures represent processes that can affect the resource (water) by producing, for example, substances (effluents) and other physical and biological agents that can consequently cause changes to the state (S) of the water resources. Society will experience either positive or negative consequences, depending on the nature and magnitude of the changes in the state. These consequences are then identified and evaluated to describe the resultant impacts (I), by means of evaluation indices.

2.4 Vulnerability Index and Parameterization

The vulnerability of the water resources of a river basin can be assessed from two perspectives: (1) main threats of water resources and its development and utilization dynamics; and (2) the basin's challenges in coping with these threats. Thus, the vulnerability index (VI) for the river basin can be expressed as:

$$VI = f(RS, DP, ES, MC)$$

where:

VI = vulnerability index; RS = resource stresses; DP = development pressures; ES = ecological insecurities; MC = management challenges.

High vulnerability is apparently linked with greater resource stresses, development pressures and ecological insecurity, as well as low management capacities. In order to quantify the vulnerability index, the indicators for each component were determined and quantified. The value of vulnerability ranges from 0 to 1.0, with 1.0 indicating the most vulnerable situation.

Resource Stresses (RS)

The general influence of water resources to vulnerability is related to water resources quantity and variation, and the pressures from them can be expressed as "scarcity" and "variation" of water resources.

Water scarcity parameter: The scarcity of water resources can be expressed in terms of annual per capita water resources availability of a region or a basin, in comparison to the generally-agreed minimum level of per capita water resources requirement ($1,700 \text{ m}^3 \cdot \text{person}^{-1}$). That is,

$$\begin{cases} RS_s = \frac{1,700 - R}{1,700} & \text{if } (R \leq 1,700) \\ RS_s = 0 & \text{if } (R > 1,700) \end{cases}$$

where:

RS_s = water scarcity parameter; and R = per capita water resources availability per year ($\text{m}^3 \cdot \text{person}^{-1} \cdot \text{year}^{-1}$).

Water variation parameter: The variation of water resources is expressed by the coefficient of variation (CV) of precipitation over the last 50 years. A CV value equal to or greater than 0.30 is taken to indicate the most vulnerable situation and expressed as:

$$\begin{cases} RS_v = CV / 0.30 & \text{if } (CV < 0.30) \\ RS_v = 1 & \text{if } (CV \geq 0.30) \end{cases}$$

where:

RS_v = water variation parameter.

Development Pressures (DP)

Water exploitation parameter: This parameter is based on the water resources development rate (i.e., ratio of water supply and total water resources availability), and is used to demonstrate a river basin's capacity for a healthy renewable process, as follows:

$$DP_e = \frac{WR_s}{WR}$$

where:

DP_e = water exploitation parameter;
 WR_s = total water supply (capacity);
 and WR = total water resources.

Safe drinking water inaccessibility parameter: This parameter encapsulates the state of social use of freshwater (i.e., how freshwater resources development facilities address the fundamental livelihood needs of the population). The contribution of safe drinking water inaccessibility parameter (DP_d) can be calculated with the following equation:

$$DP_d = \frac{P_d}{P}$$

where:

DP_d = safe drinking water inaccessibility parameter;
 P_d = population without access to improved drinking water sources; and
 P = total population.

Ecological Insecurities (ES)

The ecological health of a river basin was measured with two parameters; namely, the water quality/water pollution parameter and ecosystem deterioration parameter.

Water pollution parameter: The contribution of water pollution to water resources vulnerability is represented as the ratio of total untreated wastewater and the total water resources. The ratio equal to or greater than 15 percent of the available water is considered to represent the most vulnerable situation. Thus, the water pollution parameter (EH_p) is expressed as:

$$\begin{cases} EH_p = \frac{WW}{0.15 \cdot WR} & \text{if } (WW < 0.15 \cdot WR) \\ EH_p = 1 & \text{if } (WW \geq 0.15 \cdot WR) \end{cases}$$

where:

EH_p = water pollution parameter;
 WW = total wastewater volume (m^3); and
 WR = total water resources (m^3)

Ecosystem deterioration parameter:

This parameter is represented by the ratio of the basin area without vegetation cover to the total basin area. The area under forest and wetlands is considered as the vegetation coverage:

$$EH_e = \frac{A_d}{A}$$

where:

EH_e = ecosystem deterioration parameter;
 A_d = basin area without vegetation (forest area and wetlands) coverage (km^2); and
 A = total basin area (km^2).

Management Challenges (MC)

Management challenges are measured with the following three parameters:

Water use inefficiency parameter: This parameter is represented by the GDP produced from one cubic metre of water use, and compared with the average GDP generated per cubic metre use by selected countries. For this assessment in South East Asia, comparison was made to the top five food producers in the world, including Brazil, China, France, Mexico and USA, with a water use efficiency of US\$ 23.8 per cubic metre of water use, as follows:

$$\begin{cases} MC_e = \frac{WE_{wm} - WE}{WE_{wm}} & \text{if } (WE_{wm} > WE) \\ MC_e = 0 & \text{if } (WE_{wm} \leq WE) \end{cases}$$

where:

MC_e = water use inefficiency parameter;
 WE = GDP produced from one cubic metre of water use; and
 WE_{wm} = mean WE of selected countries.

Improved sanitation inaccessibility parameter:

The computation of this parameter is based on proportion of the population in the basin that lacks access to improved sanitation facilities, as follows:

$$MC_s = \frac{P_s}{P}$$

where:

MC_s = improved sanitation inaccessibility parameter; P_s = population without access to improved sanitation; and P = total population.

Conflict management capacity parameter:

The conflict management capacity is assessed, utilizing the matrix shown in Table 2.1. The final score of conflict management capacity parameter (MC_c) was determined by expert consultations, based on the scoring criteria.

Weighting

Based on expert consultation weights are assigned to each component of the vulnerability index to calculate the index using the following equation:

where:

VI = vulnerability index; n = number of vulnerability components; m_i = number of parameters in i^{th} component; x_{ij} = value of the j^{th} parameter in i^{th} component; w_{ij} = weight given to the j^{th} parameter in i^{th} component; and W_i = weight given to the i^{th} component.

To give the final VI value in a range from 0 to 1.0, the following rules were applied in assigning the weights: (a) the total of weights given to each indicator should equal 1.0; and (b) the total of weights given to all components should equal 1.0. As the process of determining relative weights can be biased, making comparison of the final results difficult, equal weights were assigned among indicators in the same component, as well as among different components.

Explanation of Results and Policy Recommendations

After obtaining the calculation results, further explanations were made to support the policy recommendations. To ensure a better understanding and application of VI estimates, Table 2.2 was prepared as a reference sheet to help in interpreting the VI values. From the overall VI score, general conclusion can be drawn on the state of vulnerability of the river basin, and policy recommendations can be made after further reviewing the results of the parameters in the four components (i.e., resource stresses; development pressures; ecological insecurities; management challenges), and specific policy interventions can then be recommended accordingly.

Table 2.1 | Conflict management capacity parameter assessment matrix

Category of inability	Description	Score and Criteria		
		0.0	0.125	0.25
Institutional inability	Transboundary institutional arrangement for coordinated water resource management	Strong institutional arrangement	Loose institutional arrangement	No institution existing
Agreement inability	Written/signed policy/agreement for water resource management	Concrete/detailed agreement	General agreement only	No agreement
Communication inability	Routine communication mechanism for water resource management (annual conferences etc.)	Communications at policy and operational levels	Communication only at policy level or operational level	No communication mechanism
Implementation inability	Water resource management cooperation actions	Effective implementation of river basin-wide projects/programs	With joint project/program, but poor management	No joint project/program

Table 2.2 | Interpretation of Vulnerability Index

Vulnerability Index	Interpretation
Low (0.0 - 0.2)	Indicates a healthy basin in terms of resource richness, development practice, ecological state and management capacity. No serious policy change is needed. However, it is still possible that in the basin, moderate problems exist in one or two aspects of the assessed components, and policy adjustment should be taken into account after examining the VI structure.
Moderate (0.2 - 0.4)	Indicates that the river basin is generally in a good condition toward realization of sustainable water resource management. However, it may still face high challenges in either technical support or management capacity building. Therefore, policy design of the basin should focus on the main challenges identified after examination of the VI structure, and strong policy interventions should be designed to overcome key constraints of the river basin.
High (0.4 - 0.7)	The river basin is under high stress, and great efforts should be made to design policy to provide technical support and policy back-up in order to mitigate the stress. A longer term strategic development plan should be made accordingly with focus on rebuilding up of management capacity to deal with the main threat.
Severe (0.7 - 1.0)	The river basin is highly degraded in water resource system with poor management set up. Management for the restoration of the river basin's water resource will need high commitment from both government and general public. It will be a long process for the restoration, and an integrated plan should be made at basin level with involvement from agencies in the international, national and local level.

3

Overview of Freshwater Resources of South East Asia



Figure 3.1 | South East Asia

This chapter is divided into four sections. The first section deals with the geographic and socioeconomic setting of South East Asia. The second section describes the state of the freshwater resources in the sub-region from the perspective of water resources availability, withdrawals and productivity, and access to improved drinking water sources and sanitation facilities. The third section briefs the major river basins in the sub-region. The final section describes the selected river basin, the Mekong River Basin (MRB), taken for in-depth vulnerability assessment.

3.1 Geography and Socioeconomics

The South East Asia sub-region is bounded between 10°93'-28°54'N latitude and 92°20'-141°00'E longitude. The sub-region consists of the continental margins and offshore archipelagos of Asia that lie geographically south of China and east of India. Continental South East Asia includes Myanmar, Thailand, Lao PDR, Cambodia and Vietnam, whereas the archipelagic South East Asia consists of Malaysia, Brunei, Singapore,

Indonesia, and the Philippines (Figure 3.1). The elevation ranges from sea level to 5,881 m above mean sea level at *Hkakabo Razi* of Myanmar.

The climate of South East Asia is mainly tropical, exhibiting hot and humid conditions throughout the year, and greatly influenced by monsoons originating in the South China Sea (UNEP, 2004). The sub-region has wet and dry seasons, caused by seasonal shifts in the monsoons. The tropical rain belt results in heavy precipitation during the monsoon season. The coastlines of the South East Asia sub-region border the Andaman Sea, Gulf of Thailand and South China Sea. The mountainous areas in the north, where higher altitudes lead to milder temperatures and drier landscapes, are the exception to this climate and vegetation. The regional forest cover is more than 46 per cent (well above the global average of 30 per cent) despite considerable deforestation during 1990-2003. Growing population, urbanization, logging and increasing agricultural pressure have been responsible for deforestation in the sub-region (UNEP, 2004). Brunei is the most forested country in this sub-

region, with forests covering more than 80 per cent of its land area. The relatively stable forest cover in Brunei persists because the country's economic activities largely depend on its oil and natural gas resources. The shares of arable and agricultural land in the sub-region are 14.7 and 28.5 per cent, respectively. No major changes in these two parameters are observed during 1993-2003 (see Table 3.2).

In terms of geographical area, population size and density, and per capita income, there are large variations among the South East Asian countries (Table 3.1). The sub-region comprises of small city-state of Singapore to large country like Indonesia. The sub-region occupies 3.35% of the world's total land area and is home to 8.6 per cent of the world's total population (in 2007). This uneven endowment has resulted in a higher population density (nearly 2.6 times the world average) in the sub-region. Three million people residing within one thousand km² (386 mi²) of land area identifies Singapore as the country with the highest population density in this sub-region. The share of urban population ranges from 21 (in Lao PDR) to 100 per cent (in Singapore), with a sub-regional average of 43 per cent. The average population growth of 1.6 per cent compares with world average of 1.4 per cent. Nevertheless, urban population growth rate of 3.7 per cent is considerably higher than the world average of 2.2 per cent and highlights the challenges of

Table 3.1 | Geography and population dynamics of South East Asia

Country or Region	Land area (1000 km ²)	Extreme elevations (m)	Population (millions of people)		Population growth rate (per cent)	Population density (number of people.km ⁻²)	Urban population (per cent of total population)		Urban population growth rate (per cent)
			1990	2004			2004	1990	
Brunei	5.8	0-1,850	0.3	0.3	1.4	57.9	67.3	79.0	3.7
Cambodia	177.0	0-1,801	97.0	13.8	2.5	78.0	13.0	19.0	5.5
Indonesia	1,812.0	0-5,030	178.2	217.6	1.4	120.1	31.0	47.0	4.4
Lao PDR	231.0	70-2,817	4.1	5.8	2.4	25.1	15.0	21.0	4.7
Malaysia	329.0	0-4,100	17.8	24.9	2.4	75.7	50.0	64.0	4.2
Myanmar	658.0	0-5,881	40.8	50.0	1.5	76.0	25.0	30.0	2.8
Philippines	298.0	0-2,954	61.1	81.6	2.1	273.8	49.0	62.0	3.8
Singapore	1.0	0-166	3.0	4.2	2.4	4,200.0	100.0	100.0	2.4
Thailand	511.0	0-2,576	54.6	63.7	1.1	124.7	29.0	32.0	1.7
Viet Nam	325.0	0-3,144	66.2	82.2	1.5	252.9	20.0	26.0	3.4
South East Asia	4,347.8	0-5,881	435.8	544.1	1.6	125.1	31.8	43.0	3.7
World	129,663.0	0-8,848	5,256.3	6,365.0	1.4	48.0	43.0	49.0	2.2

Source: WB (2006); FAO (2007)

urbanization in the South East Asia. It is expected that the sub-region will have three mega-cities (Bangkok, Jakarta and Metro Manila) by 2015, with each city having a population of more than ten million people (UNEP, 2004). The increasing urbanization trend will create a range of environmental problems that will increase the vulnerability of the sub-region's water resources.

Among the South East Asian countries, the Human Development Index (HDI), a measure of a country's social development, ranges from 0.553 (Lao PDR) to 0.916 (Singapore), with a sub-regional average of 0.728 (Table 3.2), suggesting unequal development in the sub-region. Three countries (Brunei; Malaysia; Singapore) exhibit high social development, with the rest of South East Asia exhibiting a medium development, based on the 2004 HDI. Economic development in South East Asia, measured as per capita Gross Domestic Product (GDP) expressed in *Purchasing Power Parity (PPP)* terms, illustrates that the sub-regional average (US\$ 4,575) is nearly 45 per cent of the world average with distinct variation among the countries in the sub-region (see Table 3.2).

Table 3.2 | Land use patterns, GDP, HDI and Gini Index of South East Asia

Country or region	Forest area (per cent)		Arable land (per cent)		Agricultural land (per cent)		GDP (PPP) (US\$.capita ⁻¹)	GDP, 2004 (million US\$)	Gini Index	HDI, 2004
	1990	2003	1990	2003	1990	2003				
Brunei	85.8	83.9	0.5	2.1	--	--	24,826	8,291.9	--	0.871
Cambodia	73.3	59.2	20.9	21.0	30.1	30.1	2,600	35,880.0	40.4	0.583
Indonesia	64.4	48.9	11.2	11.6	24.1	24.9	4,458	970,060.8	34.4	0.711
Lao PDR	75.0	59.9	3.5	4.1	7.2	8.1	2,124	12,319.2	34.6	0.553
Malaysia	68.1	63.6	5.2	5.5	22.0	24.0	12,700	316,230.0	49.2	0.805
Myanmar	59.6	49.0	14.6	15.4	15.8	16.8	1,691	84,550.0	--	0.581
Philippines	35.5	24.0	18.4	19.1	37.3	40.9	1,168	95,308.8	46.1	0.763
Singapore	3.0	3.0	1.5	1.5	3.0	3.0	32,867	138,041.4	42.5	0.916
Thailand	31.3	28.4	34.2	27.7	41.9	38.4	9,100	570,670.0	42.0	0.784
Viet Nam	28.8	39.7	16.4	20.5	20.7	29.3	3,025	248,655.0	37.0	0.709
South East Asia	56.3	46.3	14.8	14.7	28.6	28.5	4,575	2,489,007.1	40.8	0.728
World	31.6	30.5	10.8	10.8	38.4	38.4	10,361	65,950,000.0		

* For Year 2000, Source: WB (2006); FAO (2007)

Table 3.3 | State of freshwater resources in South East Asia

Country or Region	Average precipitation (billion m ³ .yr ⁻¹)	Total renewable WR (billion m ³ .yr ⁻¹)	Per capita WR, 2004 (m ³ .person ⁻¹ .yr ⁻¹)	Freshwater withdrawal (per cent)				Per capita withdrawal, 2004 (m ³ .person ⁻¹ .yr ⁻¹)	Water productivity, 1987-2004 (US\$.m ⁻³)
				Total	¹ Agri.	² Indus.	³ Dom.		
Brunei	15.7	8.5	25,449.1	1.1	--	--	--	279.9	--
Cambodia	344.6	476.1	34,500.0	0.9	97.8	0.6	1.6	310.5	1.0
Indonesia	5,146.5	2,838.0	13,042.0	2.9	91.3	0.7	8.0	378.2	2.2
Lao PDR	434.4	333.6	57,517.2	0.9	90.3	5.5	4.2	517.7	0.6
Malaysia	948.2	580.0	23,293.2	1.6	62.1	21.1	16.9	372.7	10.5
Myanmar	1,414.6	1,045.6	20,912.0	3.2	98.3	0.5	1.2	668.8	--
Philippines	704.3	479.0	5,870.1	5.9	74.0	9.4	16.6	345.3	2.8
Singapore	1.5	0.6	142.9	--	--	--	--	--	--
Thailand	832.4	409.9	6,434.9	21.2	95.0	2.5	2.5	1,364.9	1.5
Viet Nam	604.0	891.2	10,841.8	8.0	68.1	24.1	7.8	10,841.8	0.5
South East Asia	10,446.2	7,062.5	12,979.0	4.5	85.5	7.8	6.6	590.5	--
World	110,000.0	43,659.0	6,859.2	8.8	70.0	20.0	10.0	603.6	8.6

¹ Agri. – Agricultural sector, ² Indus. – Industrial sector, ³ Dom. – Domestic sector, Source: FAO (2007)

Table 3.4 | Access to improved source of drinking water and sanitation in South East Asia

Country	Population with sustainable access to improved sanitation (per cent)		Population with sustainable access to improved water source (per cent)		GDP per capita, (PPP US\$)
	1990	2004	1990	2004	
Brunei	--	--	--	--	--
Cambodia	--	17	--	41	2,423 ^b
Indonesia	46	55	72	77	3,609
Lao PDR	--	30	--	51	1,954 ^b
Malaysia	--	94	98	99	10,276
Myanmar	24	77	57	78	--
Philippines	57	72	87	85	4,689
Singapore	100	100	100	100	28,077
Thailand	80	99	95	99	8,090
Viet Nam	36	61	65	85	2,745 ^b
World	49 ^a	59 ^a	78 ^a	83 ^a	--

^a World aggregate from UN (2006); ^b Data refer to a period shorter than that specified, Source: UNDP (2006a)

Singapore, Brunei, Malaysia and Thailand are the top four countries in decreasing order in GDP.capita⁻¹, whereas Indonesia, Thailand, Malaysia and Vietnam are the top four, in decreasing order of contribution to the total regional economy. The Gini Index of the sub-region, which ranges from 34 to 49 per cent, suggests that income distribution is inclined toward equality among individuals in the countries.

3.2 State of Freshwater Resources

The South East Asia is endowed with abundant freshwater resources. The sub-region receives 9.5 per cent of the total global precipitation volume every year and is blessed with 16.2 per cent of the world's total renewable water resources (Table 3.3). Depending

on the geographic characteristics and average annual precipitation, the renewable water resources vary considerably in the sub-region (from 0.6 billion m³ in Singapore, to 2,838 billion m³ in Indonesia). Despite increasing population pressures, the per capita water resources availability exceeds 5,800 m³.person⁻¹.year⁻¹ in South East Asian countries except Singapore. Singapore, with a population density of 4,200 persons.km⁻¹ in a total land area of 1,000 km² (386 mi²) exhibits severe water stressed condition. The sub-region has an average per capita water resources of 12,980 m³.person⁻¹.year⁻¹ (1.9 times the world average value) with a distinct variation ranging from 143 m³.person⁻¹.year⁻¹ in Singapore, to 57,517 m³.person⁻¹.year⁻¹ in Lao PDR, (Table 3.3). The sub-regional total freshwater withdrawal is 4.5 per cent of the available resources, which is well below the alarming threshold withdrawal of 40 per cent proposed by the WMO (1997). The freshwater withdrawal in the South East Asian countries varies from 0.9 per cent in Cambodia and Lao PDR, to 21 per cent in Thailand. The agricultural sector is the major freshwater consumer, sharing 85.5 per cent of the total water withdrawals, followed by the industrial sector (7.8 per cent) and domestic sector (6.6 per cent). The productivity of water use, measured as GDP produced per m³ of water use, is in the range of 0.5 US\$.m⁻³ in Viet Nam, to 10.5 US\$.m⁻³ in Malaysia. The rapidly industrializing and urbanizing countries (Malaysia; Philippines; Indonesia; Thailand) exhibit

Table 3.5 | Major river basins in South East Asia

Description	River basin									
	Chao Phraya ^{1,6}	Mekong ^{2,5}	Salween ⁵	Ca/Song-Koi ⁵	Red/Song-Hong ⁵	Ma ⁵	Tami ⁵	Sepik ⁵	Fly ⁵	Irrawady ⁵
Country (per cent of total area)	Thailand	China (21.8), Cambodia (20.1); Lao PDR (25.1); Myanmar (3.5); Thailand (24.6); Vietnam (4.8)	China (52.4); Myanmar (43.8); Thailand (3.7)	Lao PDR (35.2); Vietnam (64.8)	China (53.8); Lao PDR (0.7); Viet Nam (45.5)	Lao PDR (43.6); Viet Nam (56.4)	Indonesia (97.6); Papua New Guinea (2.4)	Indonesia (3.2); Papua New Guinea (96.8)	Indonesia (6.6); Papua New Guinea (93.4)	China (4.6); India (3.8); Myanmar (91.6)
Area (km ²)	160,000	795,000	244,100	31,000	157,170	30,300	89,900	73,340	64,660	402,800
Altitude	Sea level to 2,100 msl ⁷	Just above sea level to 6,740 msl ⁷	--	--	--	--	--	--	--	--
Population	23 million	65 million [China (15 per cent); Cambodia (15 per cent); Lao PDR (8 per cent); Myanmar (1 per cent); Thailand (35 per cent); Viet Nam (26 per cent)]	4.88 million [China (50.8 per cent); Myanmar (46.1 per cent); Thailand (3.1 per cent)]	3.67 million [Lao PDR (3.3 per cent); Viet Nam (96.7 per cent)]	27.12 million [China (38.7 per cent); Lao PDR (0.1 per cent); Viet Nam (61.2 per cent)]	2.42 million [China (38.7 per cent); Lao PDR (0.1 per cent); Viet Nam (61.2 per cent)]	0.39 million [Indonesia (96.7 per cent); Papua New Guinea (3.3 per cent)]	0.77 million [Indonesia (1.3 per cent); Papua New Guinea (98.7 per cent)]	0.31 million [Indonesia (7.3 per cent); Papua New Guinea (92.7 per cent)]	35.04 million [China (5.7 per cent); India (1.3 per cent); Myanmar (93 per cent)]
Population density (persons.km ⁻²)	144	82	20	118	173	80	4	10	5	87
Rainfall (mm)	1,180	1,506 ³	1,081 ³	1,964 ³	1,423 ³	1,846 ³	3,038 ³	3,052 ³	3,781 ³	1,718 ³
Water resources (m ³ .person ⁻¹ .year ⁻¹)	1,600	7,285	29,600	3,814	3,310	7,030	334,000	114,000	451,000	14,400
Discharge (km ³ .year ⁻¹)	36.8	475	140	14	90	17	113	87	140	504
Land use (per cent)										
--Forest	35.4	43.0	43.4	--	44.4	--	--	76.3	75.8	56.2
--Grassland, savanna & shrubland	17.0	17.3	48.3	--	21.8	--	--	15.1	18.3	35.0
--Cropland	31.3	9.7	5.5	--	17.3	--	--	6.6	2.4	3.4
--Irrigated cropland	15.2	28.0	0.4	--	15.4	--	--	--	--	--
Hydropower (Megawatts)	779 (Bhumipol), 500 (Sirkit reservoirs)	4,449 (8.4 per cent of feasible potential)	--	--	--	--	--	--	--	4,016 ⁶

Source: ¹IWMI (2007a); ²MRC (2005); ³CRU (2002); ⁴WRI (2003); ⁵Oregon State University (2007); ⁶CTI and INA (1999)
⁷msl – mean sea level

relatively higher water productivities, reflecting the higher value of water in the industrial sector.

Access to safe drinking water and improved sanitation facilities, which are monitoring indicators of achievement of the Millennium Development Goals (MDGs), illustrate similar trends, since both are closely linked and dependent on similar socioeconomic factors. Except for Cambodia and Lao PDR, access to safe drinking water and improved sanitation facilities in the South East Asian countries is encouraging, compared to the world average (Table 3.4).

3.3 Main River Basins in South East Asia

More than 15 river basins of varying land and water resources characteristics drain through South East Asia. Important basin

characteristics of ten major river basins whose drainage areas exceed 30,000 km² (11,583 mi²) are presented in Table 3.5. Some of these basins are transboundary in nature. Seven are in continental South East Asia while the rest three are in archipelagic South East Asia. Data on the number of countries that share the basins, the population shared by riparian countries, population density, precipitation, water resources (in absolute and per capita terms), land cover/use pattern, and hydropower generation are shown in Table 3.5.

3.4 Description of the Selected River Basin: The Mekong

The Mekong (*Dza-chu* in Tibet; *Lancang Jiang* in China; *Mae Nam Khong* in Thailand), the longest river in South East Asia, is chosen for in-depth vulnerability

assessment. Although the Mekong River Basin is not characterized either by water shortages or open conflicts, its water issues have attracted considerable attention due to the potential threats arising out of development pressures and transboundary issues. The Mekong River and its tributaries comprise one of the largest river systems in the world, forming the vast Mekong River Basin (MRB). Ranked 12th amongst the world's great rivers, on the basis of the mean annual flow at its mouth, the river stretches from the Tibetan Plateau to the South China Sea (MRC, 2005), draining a total catchment area of 795,000 km² (306,951 mi²) within its six basin countries (China (Yunnan Province); Myanmar; Lao PDR; Thailand; Cambodia; Viet Nam) (Figure 3.3).

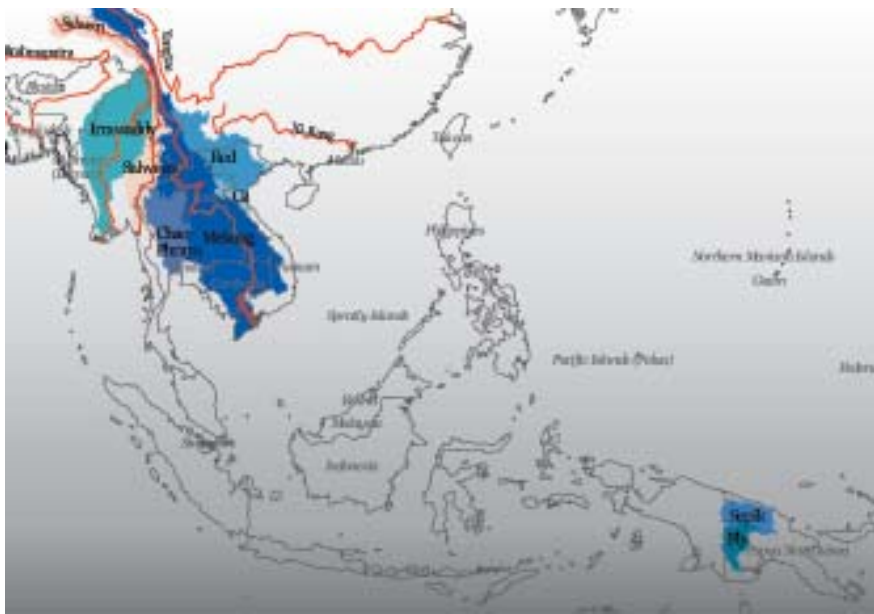


Figure 3.2 | Major river basins of South East Asia

The Mekong River Basin can be functionally divided into two parts: the Upper Mekong River Basin (UMRB) in China, and the Lower Mekong River Basin (LMRB) from Yunnan downstream to the South China Sea. The LMRB - which includes Lao PDR, Thailand, Cambodia and Viet Nam - covers about 75 per cent of the whole basin, being its most important part, both environmentally and economically. The river forms the

boundary between Lao PDR and Myanmar in the transition zone between the Upper and Lower basins. The UMRB contributes 15-20 per cent of the water that flows into the Mekong River. More specifically, the Mekong River Basin (MRB) comprises six distinctly different physio-geographic regions (Chu et al., 2003; UNEP, 2006): (i) Lancang River basin (parts of Qinghai Province; Tibet Autonomous region; Yunnan Province in China); (ii) Northern Highlands (parts of Yunnan Province in

China; Lao PDR; Myanmar; Thailand), the area in which the greatest development potential is hydropower; (iii) Korat-Sakon Plateau (parts of northern Thailand and southern Lao PDR); (iv) Eastern Highlands (parts of Lao PDR and Viet Nam), the most heavily forested area of the entire MRB and rich in biodiversity; (v) Southern Uplands (parts of Cambodia); and (vi) Lowlands (parts of Cambodia, Lao PDR, and Viet Nam, including the Mekong Delta and its associated coastal area), comprising Tonle Sap on the floodplain in Cambodia, and the Mekong delta mainly in Viet Nam, the two important landforms in the basin.

The population of the MRB is of great cultural diversity, comprising more than 70 ethnic groups living in localized communities, and most practicing subsistence agriculture. Of the estimated total MRB population of 65 million, approximately 52 million (about 80 per cent) live in the rural areas (UNEP, 2006). The population density is generally low, being 59 persons.km² in the UMRB, and 88 persons.km² in the LMRB. The density is highest (260 persons.km²) in the Vietnamese part, and lowest in Lao PDR (24 persons.km²) (UNEP, 2006). If the limits of arable land are considered, the net population densities are significantly higher, particularly in Lao PDR (465.km²) and Viet Nam (395.km²) (MRC, 2005).

According to the WRI (2003), the urban population is likely to increase significantly with the current trend of rapid urbanization. There are currently nine cities in the basin with population greater than 100,000. By 2020, an estimated one-third of the LMRB population will live in urban area, and by 2025, the LMRB population is expected to reach 90 million (MRC, 2003).

Although socioeconomic status has generally improved in the MRB, large portion of the population are poor. Infant, child and maternal mortality rates are still high in the less-developed countries of

Table 3.6 | Water resources in the Mekong River Basin

Country	Basin area (per cent of total)	Water resources (million m ³)			Annual water resources (per cent of total)
		Wet season	Dry season	Annual	
Yunnan Province, PRC	21	76,128	19,032	95,160	21
Myanmar	3	9,416	1,419	10,835	2
Lao PDR	25	145,369	16,578	161,947	35
Thailand	23	58,345	7,376	65,721	14
Cambodia	20	61,708	15,078	76,786	17
Viet Nam	8	36,942	12,353	49,295	11
Total	100	387,908	71,836	459,744	100

MRB particularly Cambodia, Lao PDR and Myanmar. Especially vulnerable are the children and women in these countries. Malaria and HIV/AIDS are the two leading public health problems (UNEP, 2006).

From livelihood perspective, one of the most important areas in the Mekong River Basin is the *Tonle Sap* or 'Grand Lake' in Cambodia. It is the largest lake in South East Asia, and one of the most productive freshwater ecosystems in the world (Kummu et al., 2008). It supports major share of Cambodia's inland fishery, with harvests that historically reached more than 90 million kg.year⁻¹ (100,000 tons.year⁻¹) (Rothert, 1995). Moreover, as a natural reservoir, Tonle Sap lessens the magnitude of flooding downstream of the lake. During the dry season, it augments irrigation and drinking water supplies downstream. The Tonle Sap provides critical spawning place and serves as habitat to many important migratory fish species, including the giant catfish caught by subsistence and commercial fishermen far up the Mekong River (Kummu et al., 2008).

Forestry and agriculture are the two major land uses in the MRB, accounting for more than 70 per cent of the basin area (UNEP, 2006). The other land use of major importance is the wetlands, which cover about nine per cent of the basin area. In addition to functioning as a water storage facility during the wet season, the wetlands play a critical role as staging posts in the flyways for migratory birds.

Agriculture is the dominant economic sector in the MRB. About 75 per cent of the basin population depends on agriculture and fisheries for livelihoods. Crop cultivation is the mainstay, with rice and other food crops grown primarily for household consumption. Rice production, based mainly on rainfed cultivation, is the most important crop in the MRB. Rice-cropping areas in the LMRB totalled about 11.7 million ha (approximately 45,200 mi²) in 1999-2000. This accounts for over half of the total rice-cropping areas of the four riparian countries in the LMRB (Chu et al., 2003).

The climate of the Mekong River Basin ranges from tropical to cool temperate, and is dominated by the Southwest Monsoon, which generates wet and dry seasons of approximately equal length. The monsoon season usually lasts from May until late-September or early-October. Later in the season, tropical cyclones occur over much of the area, with August, September and even October (in the delta) being the wettest months of the year. In the UMRB, the climate varies from tropical and subtropical monsoons in the south of Yunnan, to temperate monsoons in the north as the land rises from a mean elevation of 2,500 m (8,200 ft) to 4,000 (13,123 ft) above mean sea level on the Plateau of Tibet (MRC, 2005). Monsoon dominates the climate of LMRB which has two distinct seasons – a wet season from June to October, and a largely dry season for the rest of the year (MRC, 2003). Precipitation in the region varies with location.

The annual mean precipitation varies between 300-2,250 mm (12-87 in), and exceeds 1,000 mm (39 in) in most of the UMRB. In the LMRB, annual precipitation is high over the Northern and Eastern Highlands, being 2,000-4,000 mm (79-158 in).

The Mekong River's vast basin produces abundant surface water resources, with runoff totalling approximately 390 billion m³ during the rainy season, and 72 billion m³ during the dry season (Table 3.6). Sub-basins in Lao PDR contribute the largest water volume (about 162 billion m³.year⁻¹) to the MRB, comprising about 35 per cent of its total available water volume. Cambodia and Thailand have an annual runoff of 77 and 66 billion m³, respectively. The temporal distribution of the river flow is highly influenced by the seasonal precipitation pattern. The wet season (May to October) accounts for 85 per cent of the annual runoff.

Groundwater is an important resource in the alluvial deposits of North East Thailand and in the delta. This resource in the MRB has not yet been adequately assessed, but is thought to be a large untapped potential source of water. The estimated total potential capacity of groundwater resources is about 60 million m³.day⁻¹ and only a fraction of this amount is currently being used (Chu et al., 2003). The groundwater resources in



Figure 3.3 | The Mekong River Basin

Source: Phillips et al., 2006

Box 3.1 | Flooding in Tonle Sap, Cambodia

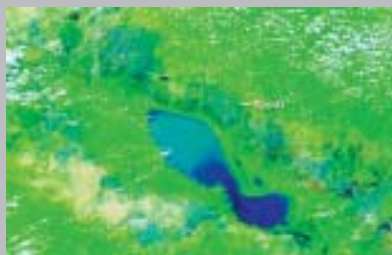


Image acquired on July 9, 2006

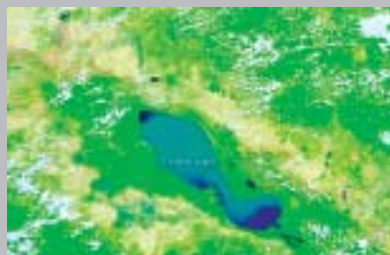


Image acquired on June 16, 2006

Source: NASA, 2007

Flooding is a common feature in MRB floodplains. The monsoon season typically lasts from June to September within the Mekong River Basin. As illustrated above, the MODIS on the Terra satellite detected flooding around Tonle Sap in Cambodia shortly after the onset of the summer monsoon. This image, taken on July 9, 2006, depicts the flood water in pale blue around the slightly darker blue lake, mainly representing a myriad of rice fields and their crops, which are starting to grow during the wet season. The natural vegetation cover appears in bright green, with the remaining agricultural areas of mainly bare soil being tan-pink in colour. The clouds are light blue and white.

In contrast, a different image taken approximately a month earlier (June 16, 2006) illustrates Great Lake area before the rain began. It shows a proportionally larger area of bare soil within the agricultural areas, where rice fields are being prepared for the wet season crop.

Box 3.2 | Risks posed by construction of hydropower dams in the MRB



Xiaowan Dam in China, the world's tallest dam

Source: Nguyen, 2003

China's ambitious plan to build a massive cascade of dams on the upper part of the Mekong River, as it tumbles through the high gorges of Yunnan Province, may pose a considerable threat to the river. The reservoir behind the third dam in the cascade, the 292 m (958 ft) high Xiaowan Dam, the world's tallest, can store more water than all the South East Asian reservoirs combined. Cambodia's Tonle Sap (Great Lake), the nursery of the lower Mekong's fish stocks, and

Viet Nam's Mekong Delta, its "rice bowl," are particularly at risk from alterations in the river's unique cycle of flood and drought (Cronin, 2007).

the basin are currently used mainly for domestic consumption and industry (e.g., food processing), while its use in agriculture is limited.

The principal feature of the MRB hydrological regime is large floods that usually begin in May, and peak in September or October, with the peak flows at Phnom Penh greater than $45,000 \text{ m}^3 \cdot \text{s}^{-1}$. The water discharge decreases after November, reaching to a minimum flow of approximately $1,500 \text{ m}^3 \cdot \text{s}^{-1}$ in March and April. The average annual total discharge is roughly 460 billion m^3 , ranking sixth highest in the world. The river inundates extensive areas of highly productive floodplains during the late wet season, including those around the Great Lake (Tonle Sap) system in Cambodia, the single largest wetland area in the LMRB (Box 3.1).

3.4.1 Development and Use of Water Resources in MRB

Agricultural sector is the major water user in the MRB. Paddy rice is the main crop grown throughout the MRB. The MRB irrigation water requirements were estimated based on crop water requirements, effective precipitation, total irrigated area (wet and dry season), and water losses during conveyance, distribution and application in the field. The total irrigation water requirements for the LMRB were about 43,700 million m^3 in 2002 and projected to increase to about 56,700 million m^3 by 2010. In terms of estimated water withdrawals for irrigated agriculture, water from the Mekong River accounts for about 94 per cent of the total withdrawals in Cambodia, 82 per cent in Lao PDR, 91 per cent in Thailand, and 86 per cent in Viet Nam, illustrating an almost total reliance on the river for agriculture in all LMRB countries.

Annual domestic and industrial water demands are expected to rise in the future. In the MRB sub-basins in Lao PDR, the demand would increase to 158 million m³ by 2010. In the MRB sub-basins of Thailand, the annual domestic and industrial water demands were about 604 million m³ and 109 million m³, respectively in 2002. These demands would increase to 834 million m³ and 336 million m³ for the domestic and industrial sectors, respectively, by 2010. In the MRB sub-basins of Cambodia, with a population growth rate of 3 per cent, the domestic and industrial water demand is projected to increase to 356 million m³ in 2010. In the Mekong River Delta provinces of Viet Nam, with the promotion of agro-based industries, the estimated domestic and industrial water requirements will increase to 874 million m³ by 2010. Overall, Thailand and Viet Nam would have the highest domestic and industrial water demands in the future.

In the UMRB, there are 5,469 km² (2,112 mi²) of farmland in the valley area of Yunnan Province, of which 39 per cent is rice fields requiring irrigation. The total water demand in 2001 was about 771.7 million m³ accounting for about 3 per cent of the total available water resources (Wu, 2004; Chen and He, 2001).

The development of hydropower within the Mekong River Basin remains contentious. The basin's rich water resources and large waterfalls provide suitable conditions for large scale hydropower exploitation. The total installed hydropower capacity is 4,449 megawatts, accounting for about 8.4 per cent of the MRB's hydropower potential (MRC, 2003). It is forecasted that aggregate power generation requirements for the Greater Mekong Sub-region (Cambodia, China, Lao PDR, Myanmar, Thailand, and Viet Nam) will increase to around 616 TWh in 2020, based on an annual growth rate of 6.9 per cent.

3.4.2 Analysis of Water Issues in the MRB

Water use in the MRB is highly seasonal. During the wet season, the quantity of available water far exceeds water demands. In contrast, during the dry season, 15 per cent of the available water is used, and in particular, water availability restricts water uses in the Mun Chi sub-basin of Thailand and Mekong delta, and the central highland sub-basins of Viet Nam.

The major abstraction of water from the basin occurs for irrigation. Irrigated rice farming is popular throughout the basin. In sub-basins within Thailand, intensification of irrigated rice system has been maximized in spite of lack of storage facilities. In Cambodia, there are significant institutional shortcomings, and in Viet Nam – where intensification of irrigated rice production system has made headway in the last decade – the Delta is a high-risk area, prone to both flooding and salt-water intrusion. Both irrigation and intensification of the agricultural production system tend to interfere with the hydrological regime.

The MRB countries are constructing/ planning scores of hydropower dams, intended to support industrialization and help lift remote areas out of poverty (see Box 3.2). Lao PDR has started construction on several of 23 planned hydropower projects. Although hydropower development is now inextricably linked to wider debates on dams and development, the predicted impacts of the proposed hydropower development include changes in river flow volume and timing, water quality deterioration and loss of biodiversity.

Although there is localized pollution near some major cities, water quality in the Mekong River is generally good. Domestic wastewater is the major source of river

pollution in North East Thailand as it is generally discharged without treatment (MRC, 2007). Industrial pollution and agricultural runoff also pose pollution problems, particularly for Thailand's Mun River basin. Phnom Penh, Cambodia's capital city discharges most of its raw sewage into nearby rivers. Agro-pollutants have been found in fish, although the dietary intake of PCBs and DDT from fish is lower in Cambodia than in other Asian countries (JSRC 1996; In et al., 1999). In the future, accelerating hydropower generating plants, industrialization, and agricultural expansion and intensification are all likely to affect Mekong River waters and water quality may be at stake for all the Mekong River Basin countries.

Of particular importance is the potential detrimental pressure on wetlands and floodplains in the MRB. Kummu et al. (2005) investigated these pressures under a High Development Scenario that considers water usage consistent with population growth in 2020; agricultural expansion to the maximum limit; and construction of two large proposed dams in the UMRB, tributary dams in the LMRB and a mainstream dam in Cambodia. They reported that under the High Development Scenario flood durations will decrease in the upper and middle reaches of the Tonle Sap Lake. In the lower reaches of the lake, the floods will linger for a longer period. The oxygen concentration in the lake waters will decrease significantly during the rising floods, and increase during the receding flood, which may be harmful to the fish (especially juveniles), and sedimentation will decrease significantly in the lake and the floodplain. Any significant decrease in sediment concentrations and sedimentation may adversely affect

productivity of the Mekong wetlands and floodplain system.

In the Mekong Delta region, floods bring much benefit in terms of improvements of the water and soil environment. It is estimated that one million ha (3,860 mi²) are inundated in the years with small floods, while bigger floods inundate up to 4 million ha (15,444 mi²) of the Mekong Delta (Thuc, 2000).

3.4.3 Climate Change Impacts in the MRB

Climate research reveals that a number of climate, ocean and geographic systems are likely to change rapidly and drastically as a result of global warming. The Tibetan Plateau – the source of the Mekong River - is one such system. Permafrost on the Tibetan Plateau begins at an average altitude of about 5,000 m (16,404 ft). This area is not yet significantly affected by direct human activity. Because the heat and moisture conditions characterizing this area are at the ecological threshold for vegetation, it is believed to be highly sensitive to global warming. The boundary between intermittent or seasonal permafrost areas on the Tibetan Plateau are likely to shift toward the centre of the Plateau, with the whole region becoming much warmer. If this occurs, it will have a significant impact on the hydrology of the Upper Mekong River Basin (UMRB), with the runoff volumes during both flood and low flow seasons decreasing dramatically (MRC, 2005). However, Arora and Boer (2001) predicted that though the runoff volumes will decrease in the UMRB, the seasonal distribution of flow will remain the same. The hydrology of the Lower Mekong River Basin is not expected to change significantly.

The daily maximum temperature will be higher by 1-3°C in January-May and lower by 1-3°C in the last four months of the year (Chinvanno, 2004). The seasons will shift and change their pattern with the dry season being dryer and longer and the rainy season starting one month later in June and lasting until November with a short break in August (UNEP, 2006).



Fishing at Tonle Sap, Cambodia

Source: Densin Roykiattisak



Inundation in Cambodia caused by Flooding of M

Source: <http://www.scienceclarified.com/landforms/F/>

Moreover, the IPCC (2007) reported that sea level rise (even a modest 20 cm rise) would result in water level contour lines in the Mekong Delta to shift 25 km (15.5 mi) toward the sea during the flood season, which will substantially aggravate flooding problems in the Mekong Delta. The salt-water will move a further 60-70 km (37-43 mi) upstream (although confined within canals) during the dry season. Although this change may not be detrimental for overall fish yields, inland movement of salt-water would significantly alter the species composition of fisheries in the Mekong Delta.

3.4.4 Transboundary Water Management in the MRB

Since 1957, four Mekong River riparian countries (Laos; Thailand; Cambodia; Viet Nam) began cooperation in managing the Lower



Mekong River into the Tonle Sap Lake
aults-to-Mountains/Floodplain.html



Fishing at the bank of Mekong River in Laos
Source: www.sxc.hu/Tanja Jans

Mekong basin through the 'Committee for the Coordination of Investigations of the Lower Mekong Basin,' or the Mekong Committee (a forerunner of the Mekong River Commission) under a statute endorsed by the United Nations. These four countries signed the 'Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin' (the Mekong Agreement) which empowered the Mekong River Commission (MRC) and established its secretariat (MRCS) in April 1995 (MRC, 2007). The 1995 Agreement includes many of the principles and provisions of the Helsinki Rules and the UN Convention on the Law of the Non-navigational Uses of International Watercourses. Article 1 of the Mekong Agreement includes the goal of optimizing benefits. Article 5 is an objective of "reasonable and equitable utilization." Article 7 states the aim "to make every effort to avoid, minimize and mitigate harmful effects that might occur to the environment . . . from the

development and use of the Mekong River Basin water resources" Each MRC member agreed to "cease immediately the alleged cause of harm," when presented by another member with proper and valid evidence of substantial damage, with Article 8 specifying the procedure for dispute resolution. An additional signed agreement requires a six-month time frame for consultation between affected countries before a proposed development can begin. The seasonality of flows in the Mekong River is addressed by differences in what is allowed during the wet and dry seasons. Further, Article 6 addresses "maintenance of flows on the mainstream." There are three specific provisions, including: (1) Flows are not to be allowed to drop below the minimum monthly natural flow during the dry season; (2) Flows are to be maintained to enable the acceptable natural reverse flow of the Tonle Sap to take place during the wet season; and (3) There is an intent to prevent average daily peak flows greater than what would

naturally occur on average during the flood season.

However, the Mekong Agreement included a number of unresolved issues related to absence of all riparian countries. China has embarked upon a major dam-building programme in the upper reaches of the Mekong. Significant impacts in terms of changes in flow patterns and sediment transport are likely, which will have bearing on the water allocation formulae agreed upon in the MRC Agreement by the four lower co-riparian countries. If the historical flows are significantly altered, the 1995 Agreement may become obsolete, and this would undermine future cooperative river basin management. Therefore, an initiative is needed to bring the missing co-riparian countries into the Mekong River Basin planning process.

4

Vulnerability Assessment

This Chapter of the report deals with vulnerability assessment of freshwater resources in the Mekong River Basin. Methodologically, the focus is on evaluating the indicators of four freshwater vulnerability components (see Chapter 2). It is hoped that unpacking the sources of vulnerability will be of importance in determining the preferred approaches of the co-riparian countries for future development.

4.1 Resource Stresses

The general influence of the availability of water resources on vulnerability is expressed as *scarcity* and *variation* of the water resources. Water scarcity refers to the inability of the water resources base to meet the demands of the basin. It is expressed as per capita water availability, and compared with the generally-accepted annual per capita water resources availability proposed by Falkenmark and Widstrand (1992) ($1,700 \text{ m}^3 \cdot \text{person}^{-1} \cdot \text{year}^{-1}$). The variation in the water resources base is expressed by the Coefficient of Variation (CV) of precipitation. The threshold is taken as 30 per cent.

In terms of annual per capita water resources availability, the Mekong River Basin averages well above that of Asia ($4,900 \text{ m}^3 \cdot \text{person}^{-1} \cdot \text{year}^{-1}$). In the Upper MRB (UMRB), the annual per capita water availability is about $10,000 \text{ m}^3 \cdot \text{person}^{-1} \cdot \text{year}^{-1}$, while it is $5,500 \text{ m}^3 \cdot \text{person}^{-1} \cdot \text{year}^{-1}$ in the Lower MRB (LMRB). The influence of the intense monsoon, however, is prominent, with more than 80 per cent of the annual runoff in the basin being generated in the monsoon season.

Although Mekong River sub-basins are expected to provide adequate levels

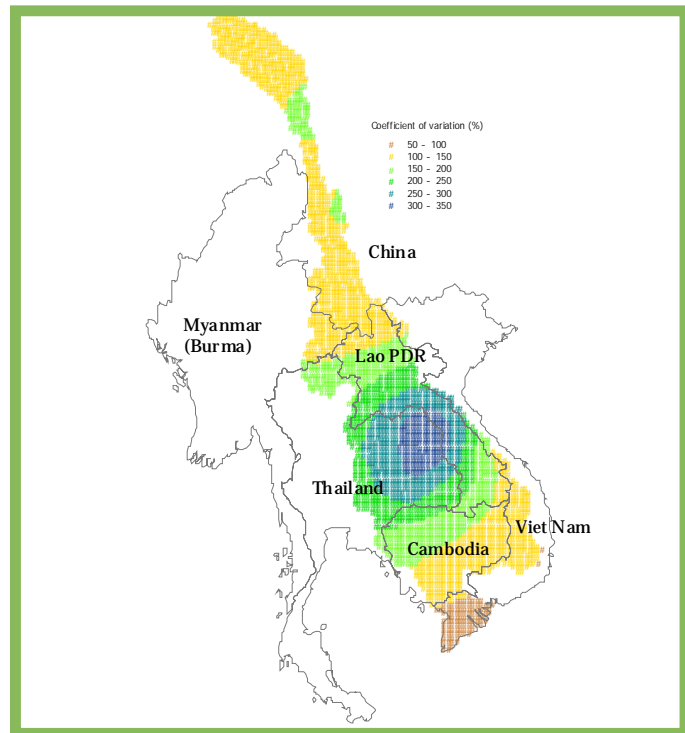


Figure 4.1 | Coefficient of variation of precipitation in December in the Mekong River Basin

of annual per capita water resources, the Lower Mekong Delta region is the most critical part, in terms of water scarcity.

Based on annual precipitation records of last 50 years, no inter-annual variations in water resources availability could be differentiated in the MRB sub-basins. To assess the monthly variations in precipitation over the years, the monthly CV values were obtained from the “World Water and Climate Atlas” (IWMI, 2007b). Large coefficient of variation (CV>100%) was found in the average monthly totals during the dry month of December-March. The variation is more pronounced in the middle part of the MRB, where the CV exceeds 200 per cent during December-January (Figure 4.1).

4.2 Development Pressures

About 97 per cent of the land area of Lao PDR and 86 per cent of Cambodia, as well as large parts of Thailand and Viet Nam, depend on the Mekong River Basin to meet their water needs. In the Yunnan Province of China, the major water supply comes from the MRB (UNEP, 2006).

The development of water resources or water exploitation is defined as the ratio of supplied water and total available water resources. The supply to three major water consuming sectors (agriculture, domestic and industry) is taken into account in this study. Water use for agriculture is estimated on the basis of crop

water requirements, effective precipitation, irrigated area, and water losses during conveyance, distribution and application in the field. Water use for domestic and industrial purposes is considered together, mainly because industrial development in the Mekong River Basin is at an early stage. The domestic and industrial water requirements are estimated based on the unit domestic and industrial demands in the countries and sub-region. The unit domestic and industrial demand is taken as 64 L.day⁻¹.person⁻¹ for Lao PDR; 115 L.day⁻¹.person⁻¹ for Thailand; 64 L.day⁻¹.person⁻¹ for Cambodia; 67 L.day⁻¹.person⁻¹ for Vietnam (MRC, 2002; VNMC, 1999).

The annual water exploitation in the MRB remains below 30 per cent in all sub-basins except the Mekong Delta and Sekong-Sesan-Srepok (Figure 4.2). During the dry season, however, the Mun Chi sub-basin in Thailand, and the Mekong Delta and Sekong-Sesan-Srepok sub-basins in Cambodia and Viet Nam use more than 40 per cent of the available water in their respective sub-basins.

The use of water for basic human needs has been further evaluated on the basis of inhabitants’ access to safe drinking water. It also reflects the adaptive capacity of society to survive in the face of scarce water resources.

Based on sub-national level data on the percentage of population without access to safe drinking water in Mekong

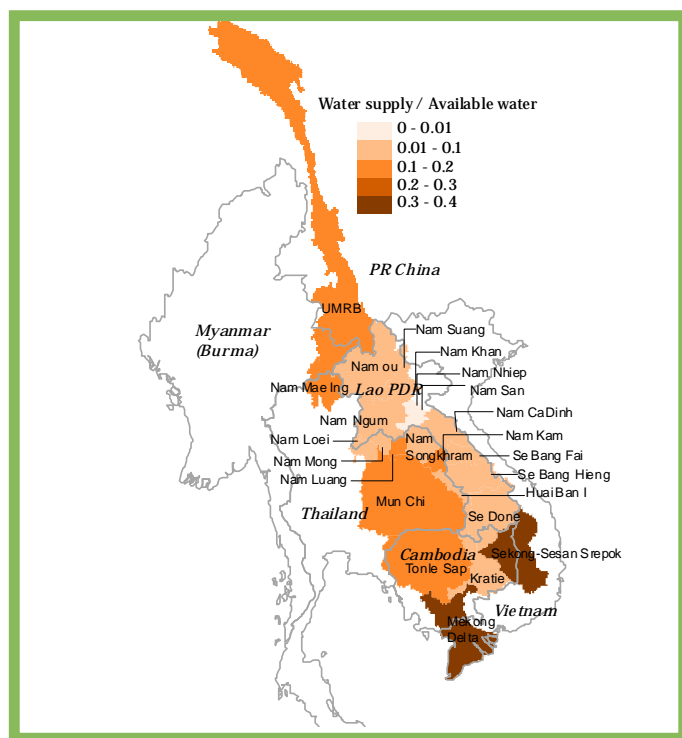


Figure 4.2 | Annual water exploitation in the Mekong River sub-basins

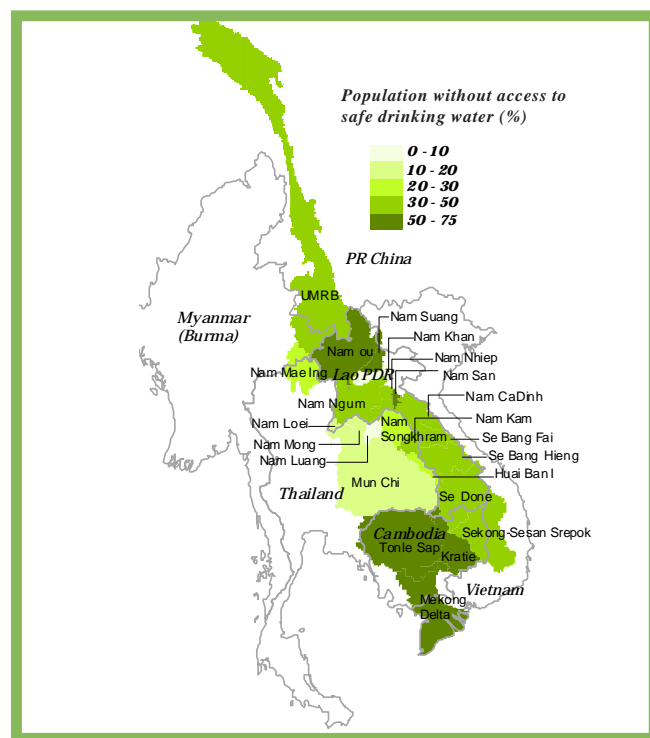


Figure 4.3 | Population without access to safe drinking water in the Mekong River sub-basins

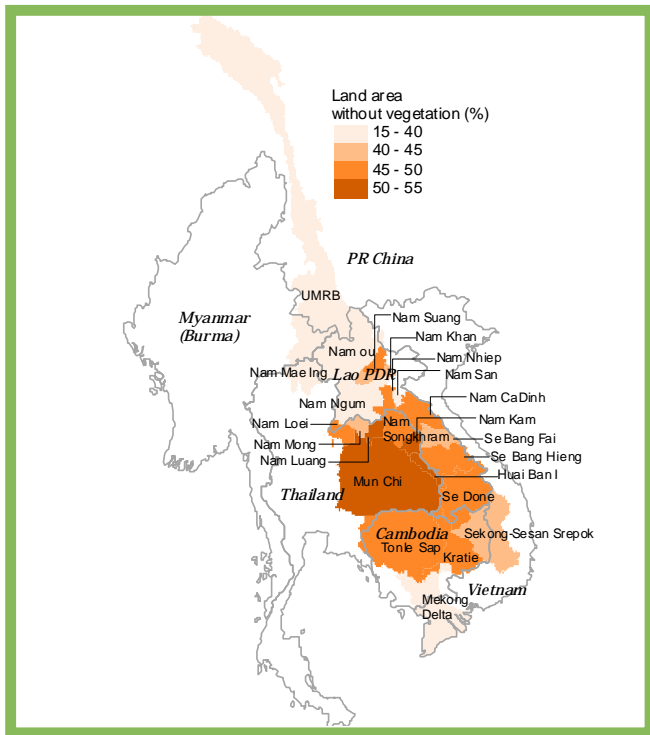


Figure 4.4 | Land area without vegetation in the Mekong River sub-basins

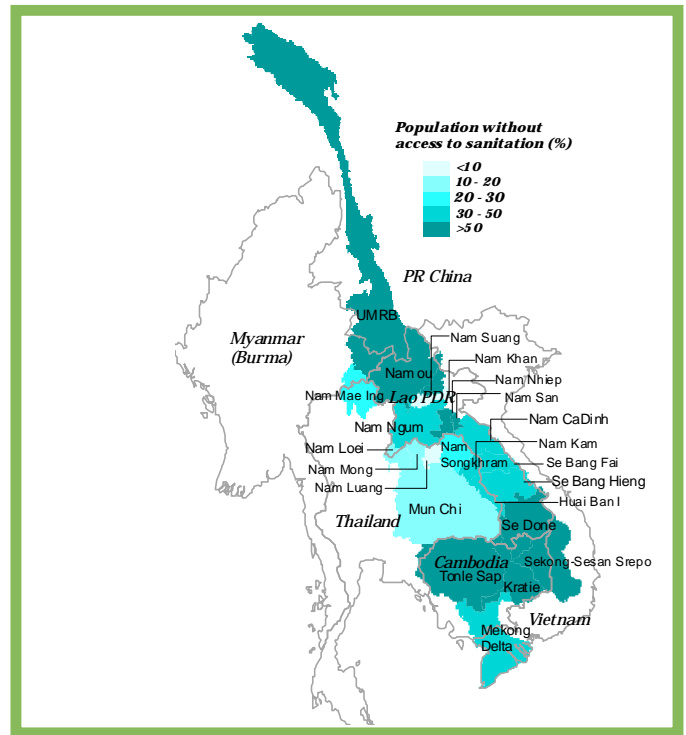


Figure 4.5 | Population without access to improved sanitation facilities in the Mekong River sub-basins

River Basin countries (Hook et al., 2003), it was estimated that 38 per cent of the population in the LMRB lacks access to safe drinking water. In the Yunnan Province of China, 33 per cent of the population lack access to improved water resources (UNDP, 2006b). On a sub-basin scale, there are six sub-basins, representing 20 per cent of the basin population, where more than 50 per cent of the population lack access to safe drinking water (Figure 4.3).

4.3 Ecological Insecurities

Maintenance of ecological health constitutes one of the prime functions of water resources. Water pollution and the lack of vegetation and wetlands have been used as indicators of the vulnerability of a water system. The degree of water pollution has been evaluated as the ratio of untreated wastewater and available water resources in a river basin. The threshold is taken as 15 per cent beyond which the water resources system is considered vulnerable.

Data on wastewater volumes were not available from within the MRB. It was assumed, therefore, that 30 per cent of the water used in the agricultural sector, and 80 per cent of the water used for domestic and industrial purposes ends up as wastewater. Estimates based on the water pollution parameter

indicate that water quality has not yet reached an alarming level, except in the Mekong Delta of the MRB. The results also conform to the findings of the GEF/MRC Water Utilization Programme (WUP) diagnostic study of water quality in the Lower Mekong basin (MRC, 2007). The study concluded that water quality at the mainstream stations during the period 1985 to 2000 was generally good or very good.

The water quality is also good in the UMRB, compared to inland basins in China. Eighty per cent of the water is in Grade I, II and III categories, which measure the drinking water resources according to the Environmental Quality Standards for surface waters of the People's Republic of China. Nevertheless, the Chinese government recognizes threat to the water quality in the lower reaches of UMRB due to accelerated industrial activity, and pursuing economic growth based on environmental sustainability (ADB, 2004).

The land use other than vegetation (forest and wetlands) may cause pollution and other deterioration of the ecosystem in river basins. Thus, the per cent of river basin without forest and wetland coverage is used as an indicator of ecosystem insecurity. Relevant data on land use were obtained from the Mekong River Commission. It is observed that most of MRB sub-basins retain above 50 per cent forest and wetland cover (Figure 4.4), which



1

1. Fishermen at work in Lotus Lake, Cambodia

Source: [www.sxc.hu/Atif Gulzar](http://www.sxc.hu/Atif%20Gulzar)

2

2. A village largely dependent on the fishery resources of Khao Laem Dam Reservoir, Sangklaburi, Thailand

Source: [Theerachai Haitook](#)



supports a rich life form that has evolved in the Cardamom and Annamite mountains of the Lower Mekong River Basin countries.

Hotspots for ecological insecurity in the MRB include the Mun Chi, Se Done, Kratie and Tonle Sap sub-basins. The latter is home to Cambodia's Tonle Sap, a lake that plays a crucial economic and environmental role in Cambodia and downstream, with about one million Cambodians estimated to rely on the lake's fisheries resources. It is anticipated that any reshaping of natural wetlands will result in the disappearance of indigenous species of plants and animals (ADB, 2004).

4.4 Management Challenges

Management of the abundant water resources of the MRB poses considerable challenge, with direct implications for the poor. Water use efficiency – represented by GDP per cubic metre of water use, indicates that the Mekong River sub-basins rank considerably lower than the top five food producing countries of the world namely; China, USA, Mexico, Brazil, and France (US \$23.8.m⁻³). The Water Use Inefficiency parameter (see Sec. 2.4) ranges between 0.44-0.99 in the MRB sub-basins.

About 29 million people currently lack access to improved sanitation facilities in the MRB. The situation is more acute in Lao PDR, Cambodia and Viet Nam, where it varies between 41-72 per cent of the population. On a sub-basin scale, the largest number of people lacking access to improved sanitation facilities (72 per cent) is in the Nam San sub-basin in Lao PDR. Although a number of water supply and sanitation programs are currently underway in the Mekong River Basin, the current levels of investment should be accelerated.

As one of the most hydro-politically unique transboundary water basin in the world, the MRB presents both opportunities and obstacles for the cooperative management of basin resources. The basin enjoys a

1 1. Life in Tonle Sap, Cambodia

Source: Densin Roykiattisak

2 2. Fish market, Vietnam

Source: Nadhika Mendhaka

long-standing river basin management organization, the Mekong River Commission (MRC), established in 1995 under the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin. The MRC comprises all MRB countries, except China and Myanmar. The 1995 Agreement includes many of the principles and provisions of the Helsinki rules and the UN Convention on the Law of the Non-navigational Uses of International Watercourses. In addition to the MRC, the region also is home to another influential cooperative organization, the Greater Mekong Sub-region (GMS). This group was formed in 1992 under the leadership and direction of the Asian Development Bank (ADB). The GMS includes all six riparian Mekong countries (China; Myanmar; Thailand; Viet Nam; Lao PDR; Cambodia). The major GMS developments include the signing of a power trade agreement in November 2002. Other GMS initiatives include promotion of regional tourism, and of trade and transport. Based on evaluation of existing transboundary institutional arrangements, policies/agreements, communication mechanisms and levels of cooperation for water resources management, the Mekong River Basin has moderate capacity to develop and manage its water resources.

4.5 Vulnerability Index

Based on the comprehensive assessment of the parameters adopted in this study, the overall Vulnerability Index (VI) was calculated, giving equal weights to the parameters; and to each sub-index, including resource stresses (RS), development pressures (DP), ecological insecurities (ES), and management challenges (MC). The calculation was carried out for the entire MRB, as well as each of its sub-basins. It was found that the overall Vulnerability Index of the MRB is 0.31, which indicates that the basin as a whole is moderately vulnerable. This finding implies that the MRB is generally in a good condition towards realization of sustainable water resources management. Table 4.1 presents the Vulnerability Parameters and Indices in the MRB and its sub-basins.

It is observed that the Vulnerability Index for the Mekong sub-basins emanates mostly from management challenges, followed by development pressures. Most of the sub-basins are faced with moderate management challenges, mainly due to the wide gap between water use efficiency in the basin and the defined world average; the lack of access to improved sanitation facility (especially Lao PDR, Cambodia and Vietnam); and the capacity of the MRC to resolve transboundary conflicts. Moderate development pressures in the sub-basins are due to relatively high degree of exploitation of water resources during the dry season, as well as lack of access to safe drinking water in the sub-basins.

Table 4.1 Sources of freshwater vulnerability in the Mekong River sub-basins

Sub-basin Name	RS	DP	ES	MC	VI
Tonle Sap	0.22	0.36	0.24	0.65	0.37
Nam Khan	0.25	0.29	0.20	0.67	0.36
Sekong-Sesan Srepok	0.14	0.41	0.22	0.65	0.35
Kratie	0.15	0.32	0.23	0.71	0.35
Mekong delta	0.23	0.43	0.13	0.59	0.34
Nam Suang	0.21	0.36	0.17	0.62	0.34
Nam San	0.12	0.27	0.25	0.71	0.34
Se Done	0.16	0.26	0.23	0.70	0.34
Nam Kam	0.22	0.26	0.26	0.60	0.33
Nam Nhiep	0.19	0.22	0.24	0.64	0.32
UMRB	0.13	0.24	0.23	0.67	0.32
Nam Ou	0.18	0.28	0.17	0.63	0.31
Se Bang Hieng	0.21	0.19	0.23	0.63	0.31
Se Bang Fai	0.21	0.19	0.21	0.64	0.31
Nam Ngum	0.18	0.23	0.20	0.60	0.30
Nam CaDinh	0.17	0.16	0.24	0.59	0.29
Nam Mae Ing	0.20	0.22	0.20	0.52	0.28
Mun Chi	0.20	0.20	0.26	0.47	0.28
Nam Loei	0.23	0.13	0.24	0.48	0.27
Nam Luang	0.29	0.09	0.25	0.43	0.27
Huai Ban I	0.24	0.13	0.26	0.41	0.26
Nam Mong	0.24	0.10	0.22	0.47	0.26
Nam Songkhram	0.16	0.13	0.23	0.46	0.24
MRB	0.15	0.25	0.22	0.6	0.31

VI: Vulnerability index
 RS: Resource stresses
 DP: Development pressures
 ES: Ecological insecurities
 MC: Management challenges

Color guide
 Low
 Moderate
 High
 Severe

5

Conclusions and Recommendations

The South East Asia sub-region comprises the countries of Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam. The sub-region elevation ranges from sea level to 5,881 m (19,295 ft) above mean sea level. The sub-region land area constitutes 3.35 per cent of the world's total land area. The largest river basin of South East Asia is the Mekong River Basin (MRB) which is home to 8.6 per cent of the world's total population, with a population density nearly 2.6 times that of the world average. The per capita GDP of the sub-region is 45 per cent of the world's average. There are, however, distinct variations in per capita GDP among the South East Asian countries, ranging from US\$ 1,168 in the Philippines to US\$ 32,867 in Singapore.

The climate of South East Asia is mainly tropical, hot and humid throughout the year, and greatly influenced by the tropical monsoons. It receives abundant precipitation and is rich in water resources availability. Despite population pressures, the annual per capita water resources availability exceeds 5,800 m³ in all South East Asian countries, except Singapore. The average annual per capita water resources is 12,980 m³, about 1.9 times the world average. The sub-regional total water withdrawal is only 4.5 per cent of the available water resources. The water withdrawal in the sub-region varies from 0.9 per cent in Cambodia and Lao PDR, to 21.2 per cent in Thailand. The agricultural sector is the major water consumer, accounting for about 85.5 per cent of the total withdrawal, followed by industrial (7.8 per cent) and domestic (6.6 per cent) sectors. The productivity of water use, measured as GDP per cubic metre of water use, is in the range of 0.5 US\$ (Viet Nam) to 10.5 US\$ (Malaysia). The rapidly-industrializing and urbanizing countries (Malaysia; Philippines; Indonesia; Thailand) exhibit relatively higher water productivity, reflecting the higher value of water in the industrial sector. Except for Cambodia and Lao PDR, access to safe drinking water and improved sanitation facilities in the South East Asia sub-region is encouraging, compared to the world average.

Given that many of the water issues in South East Asia are related to variations in seasonal flows and underdeveloped conditions, water vulnerability is assessed at the basin scale. The Mekong River Basin (MRB) is selected for in-depth analysis. Although the Mekong River Basin is not characterized by either water shortages or open conflicts, its water issues have attracted considerable attention because of the development pressures and transboundary issues. Being located largely in the tropical zone of Asia, the basin is subject to monsoon rains, which account for

about 85 per cent of its annual precipitation. This situation results in considerable variations in seasonal water availability, with the wet season (May to October) surface water availability estimated to account for 85 per cent of the annual total of 460,000 million m³.

To account for variations in water resources, development, use and management capacity within the MRB, the basin was divided into 23 sub-basins in this study. It is estimated that sub-basins in Lao PDR contribute the highest water volume (about 162,000 million m³.year⁻¹) to the MRB, accounting for about 35 per cent of the annual total water volume. Basin-wide, for each person there are more than 7,000 m³ of water annually, about equal to the world average. However, the annual per capita water availability in the Mun Chi sub-basin of the lower MRB (about 1,800 m³) barely exceeds the threshold (1,700 m³.capita⁻¹.year⁻¹) of 'water stress' conditions, as proposed by Falkenmark and Widstrand (1992).

The co-riparian countries of the MRB heavily depend on the Mekong and its tributaries for freshwater supply. People and environment in 97 per cent of the land area of Lao PDR, 86 per cent of Cambodia, and large areas of Thailand and Viet Nam, meet their water needs from the Mekong River Basin. Yet, rich endowment of water in the MRB means that annually less than 15 per cent of the available water resources are exploited. Only Mun Chi sub-basin of Thailand, and Mekong Delta and Sekong-Sesan-Srepok sub-basins of Cambodia and Viet Nam use more than 40 per cent of the available surface water during the dry season.

Water pollution generally has not reached an alarming level in the basin, except in the Mekong Delta. This situation corresponds to the absence



- 1 **1. Lao-Nippon Bridge, Mekong River, Laos**
Source: Nadhika Mendhaka
- 2 **2. Life in Java Island, Indonesia**
Source: Nadhika Mendhaka
- 3 **3. A dead fish in Chantaburi, Thailand**
Source: Nadhika Mendhaka



Color Lake, Indonesia

Source: *Nadhika Mendhaka*

of major population and industrial centres (except Phnom Penh) along the river. Even intensive agriculture is limited to parts of the Mun Chi sub-basin in Thailand, and areas of the Mekong Delta in Viet Nam.

Based on vulnerability assessment carried out for the MRB and its sub-basins, it is found that the overall Vulnerability Index is 0.31. This is indicative of a moderately vulnerable situation in the basin. On a sub-basin scale, the Tonle Sap, Nam Khan and Sekong-Sesan-Srepok are the three most vulnerable sub-basins. The vulnerability emanates mainly from the lack of management capacity and, to a lesser extent, from development pressures.

The management challenges are demonstrated by: (i) the gap between water use efficiency and the defined world average; and (ii) lack of improved sanitation facilities. Water use efficiency, in terms of GDP produced from one cubic metre water use, is US\$ 2.4 in the MRB which is much less than the US\$ 23.8.m⁻³ GDP generated by the top five food producers in the world (China; USA; Mexico; Brazil; France). The sanitation situation is most prominent in sub-basins within Lao PDR, Cambodia and Viet

Nam. For example, 72 per cent of the sub-basin population in the Nam San sub-basin within Lao PDR lack access to improved sanitation facilities.

Moderate development pressures in the sub-basins are due to higher degree of exploitation of water resources during the dry season and lack of access to safe drinking water. In six sub-basins, more than 50 per cent of the sub-basin population lack access to safe drinking water. Together they represent 20 per cent of the MRB population.

Given the contrasting scenario of abundant water availability (in volumetric terms) and lack of water services provision in the MRB, the main challenges facing policy formulation to reduce water-related vulnerability encompasses a balance between resource exploitation and maintenance of ecological health. Resource exploitation through massive infrastructure development, coupled with industrialization, should be envisaged but with caution. Though considerable attention is now given by national and international institutions to the achievements of the water supply MDG and to the Johannesburg target on sanitation, much still needs to be done, especially to remove the anomaly that exists with the sanitation goal. Moreover, the situation still calls for priority intervention and



World Heritage Rice Terraces, Banaue, Philippines

Source: *Nadhika Mendhaka*

investment on water infrastructure and good governance on water supply and sanitation.

The second key direction to reduce the water-related vulnerability of the MRB is to acknowledge the need to reach consensus on equitable water utilization (including environmental flow requirements) between the upstream and downstream co-riparian MRB countries. Considering the very high economic growth rates in parts of the MRB, and the consequent need to harness its water resources, the ongoing cooperation among the co-riparian countries should be consolidated and extended to all the countries in the basin.

The anticipated impacts of climate change and sea level rise in the Mekong River Basin show that water-related vulnerability will exacerbate due to global climate change. Yet, most countries in the basin lack the adaptive capacity to cope with future impacts and have paid inadequate attention to adaptation policies and measures. Such lack of attention can be largely attributed to the current state of

knowledge regarding likely future spatial and temporal distribution of climate and hydrological variables over the basin as a whole, let alone for specific management units considered for planning purposes. Thus, reducing the water vulnerability in the future will require additional knowledge, and research along the vein must receive much higher priority from both national governments and external support agencies.

Finally, this in-depth analysis of the Mekong River Basin provides a convincing case that balancing resource exploitation and maintenance of ecological health constitutes the key to reduced water-related vulnerability in South East Asia. It is recommended that future strategies to reduce water-related vulnerability in South East Asia should hinge on true collaboration, with real political commitment, policy debate and consensus building among the co-riparian countries.

“The challenges facing future policy formulation to reduce water-related vulnerability hinge on a balance between resources exploitation and maintenance of ecological health.”

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Glossary

A-G

Access: Access refers to the rights or entitlements of an individual or a group to obtain or make use of water resources or the services that water provide for different uses.

Actual renewable water resources: The maximum theoretical amount of water actually available for use in a basin or country, including both internal renewable resources and external renewable resources. This takes into consideration the quantity of water reserved for upstream and downstream basins or countries through formal or informal agreements or treaties, and possible reduction of external water due to upstream water withdrawals.

Adaptation: A process of societies and ecosystems dealing with water stresses, and referring to the capacity of societies and ecosystems to handle their water resources vulnerability issues.

Conflict management capacity parameter: A parameter demonstrating the capacity of river basin management system to deal with transboundary conflicts. A good management system can be assessed by its effectiveness in institutional arrangements, policy formulations, communication mechanisms, and implementation efficiency.

Domestic uses of water: Drinking water plus water withdrawn for homes, municipalities, commercial establishments, and public services (e.g. hospitals).

Ecological health: The ecosystem health of a river basin. Low wastewater discharges and high vegetation cover on the land surface generally reflect a good ecological health of a river basin.

Ecological water use: All ecosystems require water to maintain their ecological processes and associated communities of plants and animals. Environmental water requirements describe water regimes needed to sustain the ecological values of water-dependent ecosystems at a low level of risk.

Ecosystem deterioration parameter: The land ratio without vegetation coverage (forest area and wetlands) used to present the contribution of an ecosystem's deterioration to the vulnerability of its water resources.

Freshwater: The portion of water resources suitable for use by humans and most terrestrial vegetation and wildlife. It is renewable from rainfall, in the form of runoff to surface water, groundwater and water retention by soil. In this report 'water' and 'freshwater' are used synonymously.

Groundwater recharge: The total volume of water entering aquifers within a basin or country's borders from endogenous precipitation and surface water flows.

I-P

Improved sanitation: Facilities that hygienically separate human excreta from human, animal and insect contact, and include sewers and septic tanks, poor- flush latrine and simple pits, etc.

Improved sanitation accessibility parameter: A parameter typically used to measure the capacity of a management system capacity to deal with the livelihood needs of inhabitants, and refers to the percentage of population with sustainable access to improved sanitation facilities.

Improved water supply/source: These sources include piped water, public taps, boreholes or pumps, protected wells, or protected springs or rainwater.

Indicator: A parameter, or value derived from parameters, which points to, or provides information about, the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value.

Industrial uses of water: Includes cooling machinery and equipment, production of energy, cleaning and washing goods produced as ingredients in manufactured items and as a solvent.

Internal renewable water resources: The average annual flow of rivers, and the recharge of groundwater (aquifers), generated from precipitation occurring within a basin or country's borders.

Irrigation water use: The primary water use in the agricultural sector.

Management capacity: The capacity of a management system to cope with mismatches between water resources demands and water supply, by improving water use efficiency (measured as GDP produced per unit of water use) and human health conditions (measured by access to adequate sanitation facilities).

Policy: A plan of action to guide decisions and actions. The term may apply to governments, private sector organizations and groups, and individuals. The policy process includes identification of different alternatives (e.g., programs; spending priorities), and choosing among them on the basis of their potential impacts. Overall, policies can be understood as political, management, financial, and administrative mechanisms arranged to reach explicit goals. Policy alignment is the process by which consistency is achieved across a number of policies that have the potential of interfering with each other.

S-V

Safe drinking water accessibility parameter: Designed to present the state of social adaptation of freshwater use (i.e., how freshwater resources development facilities address the fundamental livelihood needs of the population). This is an integrated parameter reflecting a comprehensive impact of the coping capacity of all stakeholders.

Sectoral water withdrawals: The proportion of water resources used for one of three major purposes: agriculture, industry, and domestic uses. All water withdrawals are allocated to one of these three categories.

State: The state or status of a water system, as described by adequate structural (e.g., river morphology), physical (e.g., temperature), chemical (e.g., concentration of phosphorus and nitrogen), and biological (e.g., abundance of phytoplankton or fish) indicators.

Surface water: Water on the Earth's surface, such as in streams, rivers, lakes, or reservoirs. It includes the average annual flow of rivers generated from endogenous precipitation (precipitation occurring within a basin or country's borders). Surface water resources are usually computed by measuring or assessing the total river flow occurring in a country or a river basin on an annual basis.

Total water resources: The total freshwater available in a river basin to maintain healthy ecosystems and socioeconomic development.

Transboundary management: The framework for managing water resources across a basin and beyond political borders, including management for resolving water use conflicts.

Vulnerability: The characteristics of a water resource system's weaknesses and flaws that make the system difficult to function in the face of socioeconomic and environmental changes.

Vulnerability assessment: An investigation and analytical process to evaluate a system's sensibility to potential threats, and to identify key challenges to the system in reducing or mitigating the risks of negative consequences from adversarial actions.

W

Water resources management: Planned development, distribution and use of water resources, in accordance with predetermined objectives, and with respect to both the quantity and quality of these resources

Water pollution parameter: A parameter for measuring the ecological health of the river basin, defined as the ratio between the untreated wastewater discharges and the total water resources in a river basin.

Water quality: A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Water scarcity: A relative concept, describing the relationship between water demands and water availability. The demand may vary considerably between different countries, and different regions, within a given country or basin, depending on sectoral water uses. Thus, a country or basin with high industrial water demand, or which depend on large-scale irrigation, will be more likely to exhibit more water scarcity than a country or a basin with similar climatic conditions, but which lack of such demands.

Water scarcity parameter: The richness of the water resources in a given basin will dictate the degree to which the water demands of the population can be met. Thus, the scarcity of water resources can be expressed as the per capita water resources of a region (country or basin), compared to the generally accepted minimum level of annual per capita water resource requirement ($1,700 \text{ m}^3 \cdot \text{person}^{-1}$).

Water stress parameter: Water stress causes deterioration of freshwater resources, in terms of quantity (over-exploitation of aquifers; dry rivers; etc.) and quality (eutrophication; organic matter pollution; saline intrusion; etc.). The water stress parameter refers to the ratio of total water withdrawals to the total water resources available in a river basin.

Water use: The total quantity of water distributed to all different water users (including losses during its transportation to its point of usage). Based on the intended purposes, water use can be divided into productive (agricultural or industrial) water consumption; domestic water consumption; and ecological or environmental water consumption. Water use refers to human interactions with, and influence on, the natural hydrologic cycle, and includes elements such as water withdrawals from surface and groundwater sources; water delivery to homes and businesses; consumptive water uses; water released from wastewater treatment plants; water returned to the environment; and in-stream water uses (e.g., water for producing hydroelectric power).

Water use efficiency: The GDP produced from the use of one cubic meter of water.

Water use inefficiency parameter: A parameter representing the inefficiency of a water resources management system, as demonstrated by the gap between a basin or country's water use efficiency and the average water use of selected countries as a standard of comparison. In this report, the water use inefficiency parameter is presented as the gap between the GDP value from one cubic metre of water use in a basin, compared to the average GDP value produced from one cubic metre of water use in the world's five top food producers (Brazil; China; France; Mexico; USA).

Water variation parameter: The variation of the water resource, expressed as the coefficient of variation (CV) of annual precipitation over the last 50 years.

Water withdrawals: The gross quantity of water extracted from any source, either permanently or temporarily, for a given use. It can be either diverted to a distribution network or used directly. The term includes consumptive water uses, conveyance losses, and return flows. The total water withdrawal is the sum of the estimated water uses by the agricultural, domestic and industrial sectors.