FINAL REPORT for APN PROJECT

Project Reference: ARCP2010-01CMY-Sthiannopkao

Collaborative Research on Sustainable Urban Water Quality Management in Southeast Asian countries: Analysis of Current Status (comparative study) and Strategic Planning for Sustainable Development

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Final Report submitted to APN

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OVERVIEW OF PROJECT WORK AND OUTCOMES

Minimum 2pages (maximum 4 pages)

Non-technical summary

< 200 words >

Five analytical tools have been applied and/or developed as a strategic plan for sustainable urban water quality management by participating scientists and policy makers. Conducted by Indonesia's research team, SWOT was applied for analyzing water quality management policies in Bandung (Indonesia), Bangkok (Thailand), Ho Chi Minh City (Vietnam) and Phnom Penh (Cambodia). SWAT was applied to predict water quality in the Chao Phraya River, Thailand, by a participating USA member. WQI and WSI were developed for monitoring urban water quality in Vietnam and Thailand, respectively, by a team from Vietnam and Thailand. Furthermore, risk assessment of water quality resulting from trace metals and pathogens was conducted by researchers from Korea and Taiwan. Moreover a database for water quality, and its related data for a WQI, was built. In addition, eight persons participating in this research project have been offered at chance as an intern for their training on water sampling, analysis and management at GIST, Korea, with full financial support. Five APN meetings were organized at different Southeast Asian cities to allow both local and APN members to share and exchange their working experience and knowledge on sound management of urban water quality.

Objectives

The main objectives of the project were:

1. To develop analytical tools for policy makers to use in their decision making processes for sound urban water quality management
2. To develop a database for both scientists and policy makers' future research and decision making work
3. To build capacity of both scientists and policy makers on sustainable management of urban water quality in the Southeast Asia region

Amount received and number years supported

The Grant awarded to this project was: 2 years

US$ 40,000 for Year 1: 2009-2010

US$ 40,000 for Year 2: 2010-2011

Activity undertaken

The following activities were undertaken during two year project by APN's members.

1. Water samples were conducted in both dry and wet season in four major cities and rivers to analyze both metals and pathogen contamination as follows: (1) Phnom Penh city-Cambodia: TonleSap and Bassac rivers, (2) Bandung-Indonesia: Citarum river, (3) Bangkok-Thailand: Lower Chao Phraya river, and (4) Ho Chi Minh City-Vietnam: Saigon river.
2. Risk assessment of metals and pathogens on urban water quality was conducted.
3. SWOT (Strengths, Weaknesses, Opportunities, and Threats) was applied for water policies analyses in four studied cities.
4. SWAT (Soil and Water Assessment Tool) was applied to predict water quality.
5. Water quality indices were developed for surface water both in Vietnam and Indonesia.
6. Water Sustainable Index was developed for Bangkok, Thailand.
7. Database for urban water quality in four countries, namely Cambodia, Indonesia, Thailand and Vietnam, was built.
8. Five APN meetings were organized in Southeast Asia cities (Bangkok, Bali, Manila, Ho Chi Minh City) to disseminate research results as well as gathering ideas from both local scientists and policy makers to develop analytical tools for urban water quality management in the Southeast Asia region.

9. Eight interns from Cambodia (2), Indonesia (1), Thailand (1) and Vietnam (4) attended an internship program at the Gwangju Institute of Science and Technology, Korea, with full financial support.

Results

1. Metals Risk Assessment of Urban Water Quality

River water samples from four major Southeast Asian urban-area river systems were analyzed to determine the seasonal variation in concentrations of metals and to quantitatively evaluate their toxicity. Samples were collected from the Tonle Sap-Bassac (Cambodia), Citarum (Indonesia), lower Chao Phraya (Thailand), and Saigon (Vietnam) rivers. 19 elements, Be, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Ba, Tl, and Pb were investigated for their dissolved and total concentrations. Dissolved metal concentrations of most target elements exceeded background metal concentrations by 10- to 60-fold, indicating an enrichment of metal concentrations by urban area human activities. The variability of both dissolved and total metal concentrations were site- and time-specific, with total metal concentrations higher in the wet season than in the dry, indicating dilution effects from precipitation were non-significant. The quantitative risk assessment of metal pollution in the river waters showed potential toxicity of additive and negative effects of metal mixtures at all sampling sites in all areas studied. Cumulative criterion unit (CCU) scores in the wet season were usually higher than in the dry season in the Tonle Sap-Bassac and lower Chao Phraya rivers. The contribution of particular metals to the CCU score depended on their concentration. Al in all study areas contributed the highest percentage (72% to 85%) to total CCU scores. Cd, Cr, Cu, Pb, Ni, Zn, As, and Se had lower contributions, ranging from <1% to 19%.

2. Pathogen Risk Assessment of Urban Water Quality

In conjunction with sampling for chemical parameters, surface water samples were collected from Vietnam, Indonesia, Cambodia, and Thailand associated with large urban areas in each respective country. Water samples were processed to enumerate *Escherichia coli* and were further characterized using PCR to detect the presence of specific virulence genes. Analyzing the four countries together, the approximate mean log CFU/100 ml for *E. coli* counts in the dry season were log 4.3, while counts in the wet season were log 2.8. Of the 564 *E. coli* isolates screened for the presence of pathogenic genes, 5.3% possessed at least one virulence gene. The most common pathogenic isolates found were Shiga toxin producing strains. These results reinforce the importance of monitoring urban surface waters for fecal contamination and that *E. coli* in these environments may act as opportunistic pathogens. Such survey information is critical in establishing proper water quality parameters and may better predict the impact human pathogens may have on water usage.

3. A Review of Urban Water Quality Management: A Comparison Study of Southeast Asian Cities

The state of urban water quality for many cities in South East Asian is presently facing various typical challenges for developing countries — rapidly and uncontrolled population growth, lack of domestic and industrial waste water provision, political will of top policy makers, public awareness, capacity building, among others. In addition, appropriate water quality regulation is one of the most difficult challenges in the area of environmental policy as there are continual gaps for effective implementation, which require more attention of concerned stakeholders. This paper provides an overview on the effectiveness of urban water quality management in a selected case within Bandung, Bangkok, Ho Chi Minh and Phnom Penh. Furthermore, SWOT analysis was employed to determine strengths, weakness, opportunities and threats with urban water quality management under current conditions, and provide urgent strategies to improve urban water quality management in these regions.

4. Application of SWAT to Predict Water Quality in the Chao Phraya River Basin

The objectives of this study were 1) to develop an assessment tool for modeling water quantity and quality in the Chao Phraya river basin, 2) to predict water quantity and quality in response to climate change scenarios, 3) and to evaluate the efficiency of structural BMPs in an attempt to improving water quality in the basin. It was found that this modeling study needs to be enhanced by collecting more watershed-associated data and using high-resolution Hydrology Response Unit (HRUs) in the SWAT model. As well, more suitable monitoring stations for water quality and quantity where the tidal effect on monitoring station should be insignificant were also needed. These effects will promise more accurate and reliable modeling results, and address predictive information for effective water resources management schemes.

5. Development of Water Quality Indexes to Identify Pollutants in Vietnam's Surface Water

This study presents the first water quality indices developed to evaluate surface water in Vietnam. This basic water quality index (WQI_B) can be effectively used to evaluate the spatial and temporal variations of surface water quality as well as to identify water pollutants. The overall water quality index (WQI_O) can provide additional information, particularly on toxic substances contributing to water pollution. The water quality indices developed here were applied to the national surface water quality monitoring data taken from 1999 to 2007. Water pollutants were classified into three subcategories: organic and nutrients, particulates, and bacteria. Surface water quality in northern and central Vietnam was poor, containing organic matter, nutrients and bacteria, while water in the southern part was mainly polluted by bacteria. Trend analysis results reveal deterioration in water quality in those provinces under pressure from rapid population growth, urbanization and industrialisation. Vietnam has established an official policy of comprehensive nationwide water quality monitoring by 2020. The implementation of water quality indices can provide the guiding data for sustainable water resources management in Vietnam.

6. Development of Water Sustainable Index: A Case Study in Bangkok, Thailand

This study aims to propose the indicator for urban sustainable water management by aggregation from 3 aspects, environment, economic, and social. Thirteen sub-indices derived from those 3 aspects were used to determine the sustainability of water management of Bangkok city during the year 1999-2009. General water quality index and percentage of parameters (BOD, DO, NH_3, NO_3^-) that had not deviated from surface water quality standards were represented as indicators for environmental aspects. Water use efficiency and water infrastructure requirements were used as indicators for an economic aspect. Human health impact, water supply accessibility, wastewater treatment coverage area, population served by wastewater treatment systems, and percentage of treated wastewater volume were indicators for the social aspect. Results show that water sustainability index (WSI) calculated from 13-subindicators was 54.6 for all aspects combined with the economic sector having the highest score of 70.49, followed by environment and social aspects, respectively. To forecast water sustainability management for a Bangkok development plan in the next 10 years, 8-subindicatods were selected. It was found that WSI for the year 1999-2009 was 55.1, and was 87.7 in the year 2010-2019. The future improvement of WSI in this model was likely caused by water quality improvement of local water bodies, as plans were theoretically implemented to meet required surface water quality standards. However, achieving this task will be a challenge for the Bangkok Metropolitan Administration (BMA) because current wastewater treatment plants will still not cover the total area of Bangkok within the next 10 years.

Relevance to the APN Goals, Science Agenda and to Policy Processes

This project is in accordance with the APN science & policy agenda that it is focused on sustainable urban water quality management (APN science agenda 4 & 5; Use of resources for sustainable development and Crosscutting (Sustainable development of urban areas), respectively). In addition, this project includes policy makers from four participating countries as a project member. Furthermore, this research has developed analytical tools for policy makers to use in their decision making process for sustainable urban water quality management.

Self evaluation

In general, this APN project has received a full support from both scientists and policy makers in Southeast Asia as well as from Korea and Taiwan. However in the process of building the database, there were difficulties to collect official secondary data from participating SEA countries, especially from Cambodia. Furthermore the database building process was more intensive than predicted both regarding personnel resources (a researcher assigned to database development underwent employment changes), and regarding development of the database infrastructure (the scope of secondary data was more expansive than anticipated). At the conclusion however, these difficulties were overcome and addressed through the mutual support among APN members. Therefore, the success of this project was solely result of a very strong research team collaboration.

Potential for further work

All APN members (both scientists and policy makers) have reached an agreement to continue this project with addition funding from both APN and local sources in the following areas:

1. Developed analytical tools for urban water quality management will be tested at Bangkok Metropolitan Administration, and other SEA participating countries.
2. The current database will be expanded to cover all 10 Southeast Asian nations. New functions for data interpretation will be added.
3. Further developing of SWAT as a tool to predict urban water quality, as results of human activities as well as climate change, should be conducted.
4. Capacity building of local officers for training and use of developed analytical tools, as well as database functionality, should be organized for all 10 SEA countries in the format of workshops.
5. The study on best management practices for both non-point and point sources of contributing pollutants into rivers should be conducted.

Publications (please write the complete citation)

Pham Thi Minh Hanh, Suthipong Sthiannopkao**, Dang The Ba, Kyoung-Woong Kim, 2011, Development of water quality indices to identify water pollutants in Vietnam's surface water, **Journal of Environmental Engineering-ASCE**, Vol. 137, No. 4, pp. 273-283. (** corresponding author)

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TECHNICAL REPORT

Minimum 15-20 pages (excluding appendix)

Preface

Limit to 100 words

This report composes of six main sections. Section 1 addresses general introduction of Southeast Asia and the objectives and justification of conducting this research project. Section 2 describes different analytical tools developed within this project for the purpose of sound management of urban water quality, namely application of SWOT and SWAT to analyze water policies and quality, respectively as well as development of WQI and WSI. Section 3 reports capacity building activities both internship program and APN meetings. Section 4 describes the APN database. Section 5 concludes all study outcomes and section 6 describes future directions of this research project.

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1.0 Introduction

Southeast Asia (SEA), a sub-region of Asia, is bound between 10^{o}93´ - 28^{o}54´ N latitude and 92^{o}20´ - 141^{o}00´ E longitude. Geographically, the region is situated in the south of China, east of India and north of Australia. SEA consists of two distinctive geographic regions, namely the Mainland SEA (or Indochina) and the Maritime SEA to the east and southeast. The continental SEA comprises of Cambodia, Laos PDR, Myanmar, Thailand, Vietnam and Peninsular Malaysia. The Maritime SEA includes Brunei, East Malaysia, East Timor, Indonesia, the Philippines, and Singapore. The areal extent of the region is about 4.5 million km^2 (http://en.wikipedia.org/wiki/Southeast_Asia) with total population of 582,664 thousands in 2009 (United Nations, 2009). The urban annual growth rate of SEA (about 2.22%) during 2005 to 2010 was greater than the world value of 1.92% (United Nations, 2009). By 2050, approximately 65.4% (501,217 thousands) of total population (765,966 thousands) will be in the urban areas. The statistics clearly indicates that SEA region is becoming increasing urbanized. Moreover, this region has been the most favorable destination for industrial locations since the mid 1980s. The region's economy greatly depends on agricultures, manufacturing, and services. Malaysia, Thailand and the Philippines can be categorized as newly industrialized countries while Singapore and Brunei are affluent developed economies. The rest of SEA is still heavily dependent on agriculture. However, Vietnam is notably making steady progress in developing its industrial sectors. The SEA region manufactures textiles, electronic high-tech goods such as microprocessors, and heavy industrial products such as automobiles. Reserves of oil are also present in the region (http://en.wikipedia.org/wiki/Southeast_Asia).

Increasing in economic development as well as urbanization has brought about not only considerable business opportunities and better living patterns, in terms of the reduction in relative inequality and absolute poverty (Kummer and Turner, 1994; Litta, 2010), but it also has increased environmental pollution to such a degree that the natural ability of the environment to cope with such pollutant loadings has been overwhelmed (Litta, 2010). As most towns and cities have been developed near sources of water, such as rivers and the coastlines, several SEA rivers have been steadily degraded by either natural factors or human activities. Dixon (1990) reported that land-based activities generally caused key environmental issues including water pollution, soil degradation, as well as coastal zone euthrophication, especially in the region's mega-cities. The widespread and repeated emergence of these issues strongly suggests that current patterns of development in Southeast Asia are not sustainable.

In this present study, there are four study areas namely Phnom Penh of Cambodia, Bandung of West Java, Indonesia, Bangkok of Thailand, and Ho Chi Minh City of Vietnam. These study areas have been established and developed along the major rivers namely the Tonle Sap and Bassac Rivers, the Citarum River, the Lower Chao Phraya River, and the Saigon River of Phnom Penh, Bundung, Bangkok, and Ho Chi Minh City, respectively. With an exception of Phnom Penh, the remaining cities are the main urban centers of SEA region (http://en.wikipedia.org/wiki/Southeast_Asia).

The objectives of this study are (1) to develop analytical tools for policy makers to use in their decision making processes for sound urban water quality management, (2) to develop a database for both scientists and policy makers' future research and decision making work, and (3) to build capacity of both scientists and policy makers on sustainable management of urban water quality in the Southeast Asia region.

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2.0 Development Analytical Tools for Sustainable Urban Water Quality Management in Southeast Asia

2.1 Metals Risk Assessment of Urban Water Quality

Trace Metal Pollution Assessment of Southeast Asian Rivers

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Abstract

River water samples from four major Southeast Asian urban-area river systems were analyzed to determine the seasonal variation in concentrations of metals and to quantitatively evaluate their toxicity. Samples were collected from the Tonle Sap-Bassac (Cambodia), Citarum (Indonesia), lower Chao Phraya (Thailand), and Saigon (Vietnam) rivers. 19 elements, Be, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Ba, Tl, and Pb were investigated for their dissolved and total concentrations. Dissolved metal concentrations of most target elements exceeded background metal concentrations by 10- to 60-fold, indicating an enrichment of metal concentrations by urban area human activities. The variability of both dissolved and total metal concentrations were site- and time-specific, with total metal concentrations higher in the wet season than in the dry, indicating dilution effects from precipitation were non-significant. The quantitative risk assessment of metal pollution in the river waters showed potential toxicity of additive and negative effects of metal mixtures at all sampling sites in all areas studied. Cumulative criterion unit (CCU) scores in the wet season were usually higher than in the dry season in the Tonle Sap-Bassac and lower Chao Phraya rivers. The contribution of particular metals to the CCU score depended on their concentration. Al in all study areas contributed the highest percentage (72% to 85%) to total CCU scores. Cd, Cr, Cu, Pb, Ni, Zn, As, and Se had lower contributions, <1% to 19%.

Keywords: Trace metals, urbanization, river waters, toxicity assessment, Southeast Asia

2.1 Introduction

Rapid population growth, urbanization, and an investment boom resulting in industrial development have given rise to some serious environmental concerns in Southeast Asian (SEA) countries. Among these, metal contamination is one of the most ubiquitous, persistent, and complex chemical contamination problems faced by local societies (Luoma and Rainbow, 2008). Metal contamination in river systems has become a major environmental quality issue for many rapidly growing cities. This is because water quality and sanitation infrastructure failed to keep up with population growth and urbanization, particularly in developing countries (Reza and Singh, 2010). Rivers represent the water resources for agricultural, industrial, household, and recreational activities. Contamination of river water by metals decreases water quality and availability; such metals constitute stressors affecting water's usefulness for human needs.

From an environmental perspective, metal concentrations within river systems are the most complex of today's contamination issues. This is because of metals' accumulative nature and persistence, on top of their essential toxicity to living organisms (Luoma and Rainbow, 2008). The levels of metals in river ecosystems have increased dramatically in recent decades as a result of an expanding range of human activities (Gaillardet et al., 2003; Panagiotopoulos et al., 2010), with deleterious effects on aquatic organisms as well as on the human population in the proximity. The main pathways of exposure to metal pollution in aquatic environments are, for aquatic animals, direct contact with the water column and dietary exposure (Schmidt et al., 2010), and for humans, ingestion and dermal contact (Calderon et al., 2003). Perhaps the best known example of the effects of metal contamination is the mercury (Hg) poisoning in Minamata Bay, Japan. Thousands of people who consumed Hg-tainted shellfish and fish suffered damage to the central nervous system. The determination of metal levels in river waters is considered a leading objective in environmental research because of the close relation between toxicity and speciation (National Institute of Hydrology, 1996-97).

The growing use of water quality monitoring in Southeast Asia (SEA) has shown deterioration of river water quality to be caused by several types of pollutants, including pathogenic microorganisms, suspended solids, nutrients, and organic pollutants (Marcotullio, 2007; Visanathan and Padmasri, 2010). However, the data on metal pollution is not readily available in this region, due to certain economic limitations and the lack of tools and techniques for the accurate measurement of trace metal concentrations.

The objectives of this study were 1) to determine the concentrations of dissolved and total metals in the rivers flowing through urban areas of SEA cities, 2) to assess the seasonal variation of these dissolved and total metal concentrations in the river waters, 3) to identify the status of metal pollution using a normalization technique, and 4) to evaluate the potential toxicity of metals by using cumulative criterion units (CCU).

2.1.2 Materials and Methods

1) Study sites and sample collection

Water sample collection was conducted in four major rivers, flowing through four Southeast Asian mega-cities: Phnom Penh, Cambodia; Bandung in West Java, Indonesia; Bangkok, Thailand; and Ho Chi Minh City, Vietnam (Figure 2.1-1). In this study, mega-cities are defined as urban areas with a total population greater than 5 million inhabitants (Earth Sciences for Society, 2005). Two surface water sampling campaigns (Table 2.1-1) were conducted in 2010 to take representative samples in both dry and wet seasons. Sampling points located along the river course from the upstream to the downstream through each mega-city were selected to represent the whole urban area.

In both sampling campaigns, water samples were collected from the same locations in each monitored urban watershed. All water samples were collected at the depth of 30 cm below the surface. At each sampling location, a composite sample was obtained from a grab sample of river water collected from the middle of the river, and also from both shorelines.

Two subsamples, one for dissolved metal and one for total metal, were obtained from each sampling site. For total metal sample collection, water was collected directly into a 200 mL pre-cleaned polypropylene bottle. The sample for dissolved metal concentration was filtered through a 0.45 µm puradisc disposable filter unit. For each sample collection trip, one set consisting of a duplicate sample, a field blank, and a trip blank sample was also prepared. Immediately after collection, all samples were acidified with concentrated HNO_3 to pH<2, stored at 4°C, and then delivered to the laboratory for metal concentration analyses. All sample bottles had previously been soaked in 10% (V/V) HNO_3 overnight and afterwards rinsed with deionized water.

During each water sampling, on-site measurement of the water quality parameters of temperature, pH, turbidity, conductivity, and total dissolved solids (TDS) were also conducted.

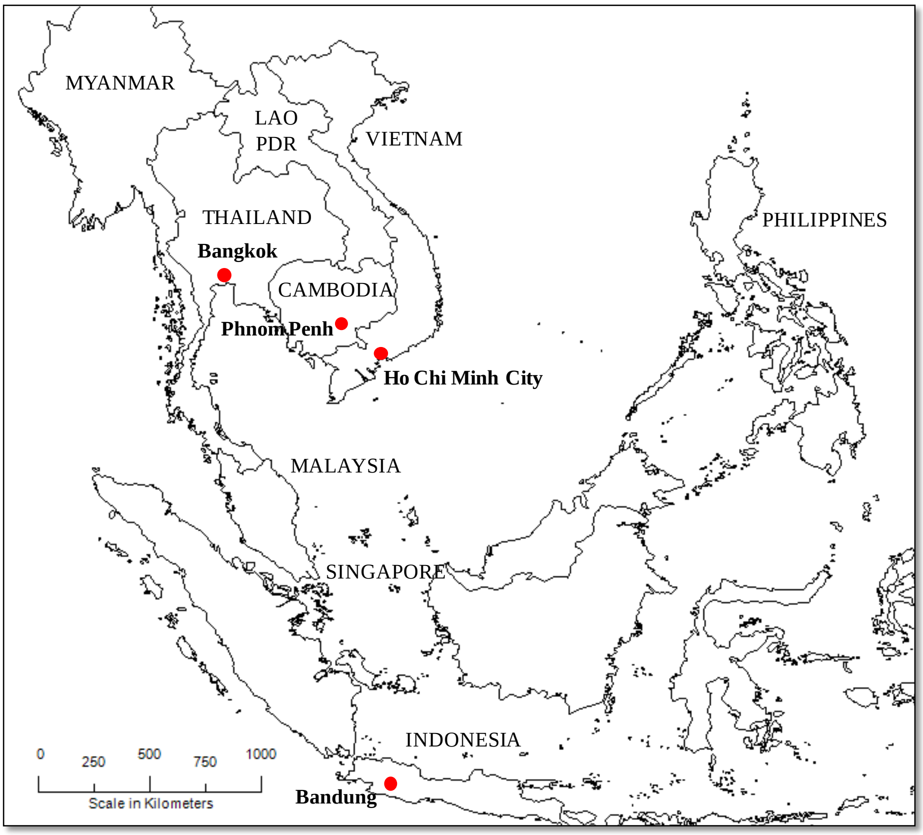

Figure 2.1-1: Site map showing location of research areas including Phnom Penh, Bandung, Bangkok, and Ho Chi Minh City.

Table 2.1-1: Summary of sampling sites and climatic conditions

Site name	Country	Main rivers	No. of sampling locations	Sampling time (dry/wet)	Annual average of climate conditions	
					Ambient temperature (°C)	Precipitation (mm)
Phnom Penh	Cambodia	Tonle Sap and Bassac	11	March/August	28.3 [a]	17 [a]
Bandung	Indonesia	Citarum	10	July/February	23.4 [b]	154 [a]
Bangkok	Thailand	lower Chao Phraya	9	April/August	28.6 [a]	159 [a]
Ho Chi Minh City	Vietnam	Saigon	10	March/October	27.9 [a]	159 [a]

Note : [a] Average climatic data in 2008 obtained from http://www.apn-seawed.com/

[b] Average climatic data in 2005 obtained from http://www.apn-seawed.com/

2) Sample preparation and analysis
Following the standard methodology for the examination of water and wastewater (APHA-AWWA-WEF, 1998), a well-mixed filtrated sample was analyzed directly for its dissolved metal concentrations. For the total metal concentration analysis, a small modification was applied; 50 mL of well-mixed acid-preserved sample was transferred into a pre-cleaned polypropylene tube and 2.5 mL of concentrated HNO_3 was added into the sample, after which the sample was covered with a ribbed watch glass, brought to a slow boil, and evaporated in a block heater to the lowest volume possible (approximately 5-10 mL). The tube walls and watch glass cover were washed down with deionized water and sample volume was then brought back to the original volume of 50 mL. Finally, the sample was mixed thoroughly and analyzed for total metal concentrations.

Total concentrations of 19 elements, including Be, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Ba, Tl, and Pb were analyzed by inductively coupled plasma mass spectroscopy (Agilent 7500ce ICP-MS) and inductively coupled plasma optical emission spectroscopy (Perkin Elmer Optical 5300 DV ICP-OES).

The detection limits for all 19 target analytes were 0.03 µg L^{-1} Be, 0.33 µg L^{-1} Al, 0.08 µg L^{-1} Ti, 0.01 µg L^{-1} V, 0.01 µg L^{-1} Cr, 0.06 µg L^{-1} Mn, 0.63 µg L^{-1} Fe, 0.01 µg L^{-1} Co, 0.02 µg L^{-1} Ni, 0.08 µg L^{-1} Cu, 0.48 µg L^{-1} Zn, 0.04 µg L^{-1} As, 0.02 µg L^{-1} Se, 0.02 µg L^{-1} Mo, 0.02 µg L^{-1} Ag, 0.008 µg L^{-1} Cd, 0.04 µg L^{-1} Ba, 0.001 µg L^{-1} Tl, and 0.01 µg L^{-1} Pb. Quality control and quality assurance for all instrumental analyses were conducted for each batch of 20 samples by using an analytical blank sample, an external standard, and standard reference material (SRM 1643e, NIST). The relative standard deviations from repeated measurements for both external standards and SRM were within 5% for all measured metals.

3) Statistical analysis
SPSS 15.0 for Windows software package was used to perform all statistical analyses on the data, including maximums and minimums, means, medians, and standard errors. Prior to the statistical analyses, all data sets were checked for normality of distribution by the Shapiro-Wilk test. Data for few of the parameters could be fitted to a normal distribution with 95% confidence. Therefore, the Mann-Whitney U-Test was performed to determine whether there was a significant seasonal difference in dissolved and total metal concentrations.

3) Normalization technique

The normalization to a reference element was used as a promising tool for interpreting metal concentrations in river waters in this region. The method was based on a statistical analysis of information from the database of trace element concentration in world natural river systems. The method of normalization consists of establishing the mathematical relationship between metal concentrations and the concentrations of conservative elements (Sakan et al., 2010). Generally, aluminum (Al) or iron (Fe) represents a representative method of determining whether the environment is enriched with metals when compared to samples of natural conditions (Summers et al., 1996). Both Al and Fe concentrations have been used successfully to normalize metal concentrations because they have several common characteristics including 1) they are among the most abundant crustal elements, 2) the ratio of metal concentrations to either Al or Fe concentrations are relatively constant in the Earth's crust, 3) and that neither Al nor Fe is likely to have a significant anthropogenic source (Schropp, 1988; Schropp et al., 1990; Summers et al., 1996). The main assumption for the application of a normalization technique is the existence of a linear relationship between the normalizer and other metals (Sakan et al., 2010). If these prerequisites are valid, then it is possible to produce a scatter plot of the metal in question and normalizer concentrations.

This assessment technique was proposed that it can easily be used to distinguish natural from enriched metal concentrations in river systems. The normalization technique required a constant variance and normal distribution of the data. Preliminary examination of the metal data indicated that log transformation was necessary. After log transformation, simple linear regression analyses were performed on the resulting data set. From the results of the regressions, 95% prediction limits were calculated. Regression results and prediction limits were then used to evaluate the state of metal concentrations (natural concentrations or enriched concentrations) in the river waters from all study areas. The water is judged to be natural or metal-enriched depending on where the points lie relative to the regression lines and prediction limits. All points which are found in the 95% confidence bands of prediction limits can be characterized as dissolved trace metals originated from natural river systems. If a point falls above the upper prediction limit, the river water is considered to be metal enriched. The greater distance above the prediction limit indicates a greater degree of enrichment (Schropp, 1988; Sakan et al., 2010).

4) Quantitative risk evaluation for potential toxicity of metals

The cumulative criterion unit (CCU) proposed by Clements et al. (2000) was used to evaluate the additive chronic toxicity of metal mixtures on aquatic organisms. It expresses as a single variable the possible additive chronic effects of metals at any sampling site. Since the toxicity of metals can be affected by several water characteristics, including water hardness, Ca/Mg ratios, dissolved organic carbon (DOC), and pH, CCU is calculated according to total metal concentration and US EPA hardness-adjusted criterion continuous concentration (CCC) values for toxicity, as shown in the following equation.

$$CCU = \sum_{i=1}^{n} m_i / c_i$$

Here, m_i is the total metal concentration and c_i is the US EPA hardness-adjusted CCC value for the *i*th metal. A CCU of 1.0 represents a conservative estimate of the total metal concentration that is likely to cause harmful effects to aquatic organisms (Clements et al., 2000). Recently, Loayza-Muto et al. (2010) have scaled the scores of cumulative criterion units into 4 levels: <1.0, no adverse effects; 1.0 to 2.0, adverse effects; 2.0 to 10.0, significant mortality to sensitive species and altered benthic community composition expected; and >10.0, highest toxicity.

2.1.3 Results and Discussion

1) General water characteristics

Both physical and chemical characteristics of river water from all areas studied are summarized in Table 2.1-2; river water characteristics were revealed to be site specific. In brief, the temperature of river water (Table 2.1-2) was generally lower than the ambient air temperature (Table 2.1-1) and varied from 29.0 to 30.0^{o}C. In terms of pH, the Tonle Sap-Bassac Rivers, the Citarum River, and the lower Chao Phraya River can be considered as neutral, with pH values around 7. However, the pH of the Saigon River at most sampling sites was found to be acidic, with pH values ranging from 5.4 to 8.0 (at a single site). The water samples collected from the Saigon River during the wet season had a lower pH than samples collected during the dry season. This may be caused by erosion of an acidic sulfate soil carried by surface runoff, especially in the wet season, to canals in the middle part of the Saigon River system. Water clarity measured by turbidity units indicated that among the four river systems, water collected from the Tonle Sap-Bassac Rivers contained the highest amounts of suspended and colloidal matter. Silt, finely divided organic and inorganic matter, as well as plankton and other microscopic organisms are major constituents causing turbid waters (APHA-AWWA-WEF, 1998). The turbidity of waters is important in terms of treatment costs and aesthetic issues for a water supply system, as well as the overall condition and productivity of a body of water. In the United States, regulations require that a drinking water treatment facility which employs conventional or direct filtration methods can process only water with less than 1.0 nephelometric turbidity units (NTU) (US EPA, 2009). High turbidity levels, moreover, are often associated with higher levels of disease-causing organisms that can cause nausea, cramps, and diarrhea. As another aspect of turbidity, the more dissolved ionic solutes in water, the greater its electrical conductivity

(EC). However, the relationship between conductivity and total suspended solids (TDS) is not directly linear. Typical fresh water generally contains <1500 mg L^{-1} TDS (Masters and Ela, 2007). In the present study, it was found that water collected from the lower Chao Phraya River had both the highest conductivity (ranging from 353.0 to 6320.0 µS cm^{-1}) and highest TDS (from 216.0 to 12,108.0 mg L^{-1}). The highest conductivity found in the lower Chao Phraya River (6320.0 µS cm^{-1}) was about 4 times higher than the conductivity of potable waters in the United States (50 to 1500 µS cm^{-1}) (APHA-AWWA-WEF, 1998) and 2.5 times higher than that in Europe (<2500 µS cm^{-1}) (European Commission, 1998). Conductivity of domestic household wastewater, it has been observed, tends to be near that of the local water supply. Therefore, high conductivity of the lower Chao Phraya River might indicate contamination from sources other than domestic wastewater, such as industrial wastes. APHA-AWWA-WEF (1998) observed as well that some industrial wastes have conductivities above 10,000 µS cm^{-1}. Even though TDS is not generally considered a primary pollutant, it is used as an indication of the aesthetic characteristics of drinking water (European Commission, 1998). Water collected from the three other river systems, the Tonle Sap-Bassac, the Citarum, and the Saigon, were found to have low conductivity and low TDS concentrations.

Table 2.1-1: General water quality characteristics (mean±standard error) measured at the time of sample collection

River	Physical characteristics		Chemical characteristics		
	Temperature (°C)	Turbidity (NTU)	pH	Conductivity (EC) (µS cm^{-1})	TDS
Tonle Sap-Bassac	28.9±0.31	106.5±18.2	7.2±0.10	853.8±5.01	51.2±3.02
Citarum	25.1±0.25	NA[a]	7.2±0.03	NA[a]	144.5±7.08
Lower Chao Phraya	29.9±0.4	26.7±4.0	7.2±0.07	2037±475.69	2877.7±924.25
Saigon	29.8±0.33	47.7±10.4	6.4±0.14	383±118.77	2.5±0.76

Note: [a] NA = not analyzed

2) Dissolved metal concentrations in river water

As a fundamental principle, knowledge of the natural background concentrations of the metals in river water is needed to assess the degree of metal pollution. While surveys of dissolved metal concentrations in natural waters have been going on since the 1970s (Luoma and Rainbow, 2008), rivers in Asia have received relatively little attention (Gaillardet et al., 2003). Many elements, in particular trace elements, have been extracted from their sites of natural occurrence and employed, over thousands of years, in human activities. The changing distributions of trace elements can be seen as highly sensitive indexes of human impact, from a local to global scale (Gaillardet et al., 2003). Knowing the natural background concentrations is therefore essential for pollution impact studies. The world average dissolved metal concentrations have been used in many studies as the natural background concentrations because dissolved concentrations are not especially different among river systems (Luoma and Rainbow, 2008). Sindren et al. (2007) concluded that anthropogenic enrichment of metals in a river system can be revealed by metal concentrations exceeding the range of background concentrations.

The Tonle Sap-Bassac Rivers

When comparing the analysis of dissolved metal concentrations in the Tonle Sap-Bassac Rivers with the average dissolved metal concentrations of world natural river systems (as background concentrations) (Gaillardet et al., 2003; Rauch and Pacyna, 2009) two metals, V and As, were, respectively, about 1.27 and 2.95 times higher than their background concentrations (Table 2.1-3).

The higher than background value concentrations for V and As appeared along the water course at all sampling sites in both dry and wet seasons. Dissolved V and As concentrations in the dry season were, respectively, about 1.0 to 1.6 times and 2.5 to 4.4 times higher than those same metal concentrations in the wet season. The other dissolved metal concentrations were found to be lower than their background concentrations and present at trace levels (<0.1%).

Table 2.1-3: Concentrations of metals (μg L^{-1}) in the Tonle Sap-Bassac Rivers

	Be	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Pb
Dissolved metal concentrations																			
Min.	ND	ND	ND	0.67	0.10	ND	ND	0.01	ND	0.25	ND	0.69	ND	0.02	ND	ND	2.34	ND	ND
Max.	ND	34.61	0.72	1.29	0.46	4.15	22.76	0.16	0.56	1.62	ND	3.46	0.12	0.56	ND	ND	15.13	0.01	0.17
Average	-	10.73	0.35	0.90	0.29	0.83	10.05	0.05	0.28	0.99	-	1.83	0.02	0.23	-	-	7.03	0.00	0.04
Median	-	7.98	0.33	0.83	0.30	0.43	10.96	0.03	0.33	1.06	-	1.57	0.00	0.20	-	-	5.03	0.00	0.02
SE	-	2.22	0.06	0.04	0.03	0.23	1.55	0.01	0.04	0.09	-	0.23	0.01	0.14	-	-	1.00	0.00	0.01
World average		32.00	0.49	0.71	0.85	34.00	66.00	0.15	0.80	1.50	0.60	0.62		0.42		0.08	23.00		0.08
Total metal concentrations																			
Min.	ND	518.72	5.74	1.83	1.04	18.62	323.05	1.73	0.92	1.73	5.43	2.26	ND	0.15	ND	ND	19.56	ND	0.50
Max.	0.31	21320.00	117.50	17.82	13.69	331.50	13820.00	10.67	9.10	10.67	30.17	5.76	0.19	1.21	0.52	0.22	78.85	0.15	7.88
Average	0.13	7820.90	43.39	8.03	6.41	117.30	5367.22	6.11	4.58	6.11	16.21	3.74	0.12	0.34	0.04	0.05	45.95	0.05	3.66
Median	0.14	4124.10	28.73	6.54	6.65	80.86	4138.59	6.39	4.31	6.39	15.70	3.48	0.13	0.30	0.00	0.05	43.48	0.06	3.22
SE	0.03	1658.21	7.93	1.28	0.82	22.36	1090.29	0.61	0.53	0.61	1.59	0.21	0.01	0.05	0.02	0.01	4.74	0.01	0.53
NPDWR[a]	4				100							10	50			5	2000	2	15
NSDWR[b]		50-200				50	300			1000	5000				100				

Note: [a] NPDWR: National Primary Drinking Water Regulations

[b] NSDWR: National Secondary Drinking Water Regulations

The Citarum River

As Table 4 reveals, dissolved concentrations of almost all metals (Al, Ti, V, Mn, Fe, Co, Cu, Zn, As, Mo, Ba, Ni, and Pb) in the Citarum River were higher than their background concentrations (Gaillardet et al., 2003; Rauch and Pacyna, 2009), with average multiples of background concentrations of 2.8 (Al), 35.8 (Ti), 6.9 (V), 12.3 (Mn), 1.8 (Fe), 5.5 (Co), 1.7 (Cu), 15.5 (Zn), 2.0 (As), 1.5 (Mo), 1.2 (Ba), 3.8 (Ni), and 3.8 (Pb) (Table 2.1-4). The results of dissolved metal concentrations clearly indicate metal enrichment in the Citarum River system. Only dissolved Cr and Cd were present in lower than background value concentrations.

The lower Chao Phraya River

The multiples of dissolved concentrations times their background concentrations of V, Mn, Co, Cu, Zn, As, Mo, Ba, Ni, and Pb in the lower Chao Phraya River of Bangkok were approximately 2.3 (V), 4.1 (Mn), 2.5 (Co), 1.6 (Cu), 54.6 (Zn), 3.9 (As), 3.0 (Mo), 5.8 (Ba), 6.9 (Ni), and 3.8 (Pb) (Gaillardet et al., 2003; Rauch and Pacyna, 2009) (Table 2.1-5). Generally, dissolved concentrations of the metals listed above were found to be 1-2 times higher in the dry season than in the wet. Only dissolved concentrations of Mn, Cu, and Pb were higher in water samples collected in the wet season than in the dry season. Elements with dissolved concentrations lower than their background values were Al, Ti, Cr, Fe, and Cd.

The Saigon River

In the Saigon River, all dissolved metal concentrations except Ba were higher than their elemental background concentrations in the undisturbed river systems (Table 2.1-6) (Gaillardet et al., 2003; Rauch and Pacyna, 2009). Dissolved Zn concentrations were significantly higher (about 122 times) than the background value. Dissolved Al, Ti, V, Cr, Mn, Fe, Co, Cu, As, Mo, Ni, and Pb in the Saigon River had multiples of about 7.6 (Al), 3.7 (Ti), 2.0 (V), 1.9 (Cr), 2.7 (Mn), 5.6 (Fe), 3.5 (Co), 3.0 (Cu), 1.2 (As), 1.4 (Mo), 2.6 (Ni), and 16.6 (Pb) times higher than their background values (Table 2.1-6).

Overall, the results of dissolved metal concentrations in river waters for the present study agree well with Elbaz-Poulichet et al. (1996), who found a greater anthropogenic imprint of dissolved metal concentrations by a factor of 2 to 4 times unpolluted levels. According to Luoma and Rainbow (2008), metals that are relatively abundant in the Earth's crust change least in response to human inputs. Concentrations of elements that are relatively rare in the Earth, such as Cd, Ni, Cu, Zn, and Pb, are more greatly influenced.

Table 2.1-4: Concentrations of metals (µg L^{-1}) in the Citarum River

	Be	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Pb
Dissolved metal concentrations																			
Min.	ND	62.69	0.51	1.67	ND	6.89	17.65	0.19	0.17	0.51	3.28	0.52	0.04	0.20	ND	ND	7.07	ND	0.10
Max.	0.06	125.60	13.36	8.38	2.80	638.00	557.40	1.25	9.66	6.94	44.26	5.55	0.63	0.95	0.26	0.06	68.14	0.09	1.30
Average	0.01	90.50	3.80	4.31	0.76	261.54	229.27	0.59	2.31	2.54	11.93	2.63	0.20	0.63	0.06	0.02	29.61	0.04	0.48
Median	0.01	86.52	2.75	3.84	0.79	195.10	193.35	0.47	1.45	2.23	10.02	2.25	0.17	0.69	0.04	0.02	32.37	0.04	0.44
SE	0.004	6.19	0.69	0.34	0.13	55.82	34.78	0.08	0.55	0.28	2.30	0.37	0.03	0.05	0.02	0.004	3.42	0.01	0.07
World average		32.00	0.49	0.71	0.85	34.00	66.00	0.15	0.80	1.50	0.60	0.62		0.42		0.08	23.00		0.08
Total metal concentrations																			
Min.	ND	9.37[a]	9.50	6.93	2.41	113.4	8.50[a]	0.78	1.17	2.65	18.13	1.30	0.10	0.20	ND	ND	10.06	0.001	0.26
Max.	0.30	37.56[a]	624.2	38.44	20.56	1064.00	20.00[a]	6.40	21.21	24.17	151.90	5.55	0.63	2.07	0.26	0.10	86.76	0.21	7.63
Average	0.11	17.20[a]	303.66	21.99	9.45	520.53	12.577[a]	3.57	8.61	15.29	55.41	3.05	0.24	0.78	0.06	0.04	44.12	0.09	3.15
Median	0.09	13.46[a]	320.30	22.61	8.19	559.50	11.75[a]	3.67	8.61	14.88	46.68	2.62	0.22	0.77	0.04	0.04	42.14	0.09	2.10
SE	0.02	3.26	30.67	1.80	1.24	53.00	1.27	0.34	1.23	1.11	7.29	0.29	0.03	0.08	0.02	0.01	4.89	0.01	0.65
National water quality standard								200		20	5	1000	50			10			30

Note: [a] Elemental concentrations are indicated in the unit of mg L^{-1}

Table 2.1-5: Concentrations of metals (μg L^{-1}) in the lower Chao Phraya River

	Be	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Pb
Dissolved metal concentrations																			
Min.	ND	8.53	ND	0.84	0.29	6.13	9.85	0.15	3.19	1.03	22.98	1.96	0.04	0.76	ND	ND	104.00	0.16	0.16
Max.	0.09	75.68	0.92	1.57	1.37	779.3	331.60	1.94	7.45	9.48	56.92	3.23	0.28	1.47	0.34	0.04	174.30	0.86	0.86
Average	0.01	24.30	0.28	1.66	0.66	138.91	54.11	0.37	5.48	2.39	32.77	2.41	0.11	1.27	0.14	0.02	132.23	0.30	0.30
Median	0.00	25.63	0.31	1.35	1.35	25.83	76.57	0.19	5.31	2.72	33.45	2.08	0.11	0.98	0.09	0.01	137.70	0.34	0.34
SE	0.01	7.70	0.11	0.09	0.09	110.49	34.22	0.21	0.46	0.83	3.89	0.15	0.03	0.08	0.04	0.004	8.44	0.07	0.07
World average		32.00	0.49	0.71	0.85	34.00	66.00	0.15	0.80	1.50	0.60	0.62		0.42		0.08	23.00		0.08
Total metal concentrations																			
Min.	ND	32.25	ND	1.22	0.43	ND	ND	0.08	3.94	1.12	28.06	2.24	ND	0.72	ND	ND	104.40	ND	0.32
Max.	0.50	267.83	1.32	2.64	6.49	1189.00	409.60	2.89	23.54	14.22	160.60	5.23	0.68	3.25	2.50	0.32	255.50	0.30	1.88
Average	0.10	100.39	0.54	2.17	1.94	207.21	94.75	0.59	7.11	4.27	52.49	3.19	0.20	1.79	0.32	0.09	174.57	0.09	0.72
Median	0.16	61.82	0.48	2.46	1.16	38.89	105.60	0.54	6.57	4.23	52.69	3.53	0.21	1.71	0.20	0.20	203.30	0.15	0.54
SE	0.03	15.28	0.08	0.11	0.42	92.84	24.97	0.17	1.04	0.65	7.48	0.19	0.04	0.14	0.13	0.03	10.40	0.03	0.10
Surface water quality standard						1000			100	100	1000	10				5[a] 50[b]			50

Note: [a] is for hardness <100 mg/L, [b] is for hardness >100 mg/L

Table 2.1-6: Concentrations of metals (μg L^{-1}) in the Saigon River

	Be	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Ba	Tl	Pb
Dissolved metal concentrations																			
Min.	ND	5.99	0.09	0.24	ND	9.03	7.59	0.08	ND	0.55	5.38	0.24	ND	0.08	ND	0.20	9.28	ND	ND
Max.	0.08	2507.00	5.77	3.04	8.98	179.80	2590.00	1.30	3.90	16.51	311.10	1.26	0.61	1.43	2.24	245.00	33.08	0.03	6.55
Average	0.01	243.81	1.80	1.43	1.57	89.97	368.84	0.53	2.06	4.47	73.25	0.73	0.14	0.60	0.36	40.52	19.29	0.00	1.33
Median	0.00	70.04	1.24	1.55	1.13	72.49	258.08	0.50	2.26	3.23	49.53	0.69	0.00	0.52	0.09	0.87	19.71	0.00	0.57
SE	0.01	134.80	0.42	0.17	0.51	11.41	142.38	0.08	0.26	1.03	19.36	0.07	0.04	0.09	0.15	81.24	1.76	0.00	0.40
World average		32.00	0.49	0.71	0.85	34.00	66.00	0.15	0.80	1.50	0.60	0.62		0.42		0.08	23.00		0.08
Total metal concentrations																			
Min.	ND	69.68	2.00	0.33	1.62	16.78	199.10	0.13	0.31	2.48	12.30	0.44	ND	0.22	0.03	0.15	9.77	ND	0.83
Max.	0.48	11111.47	143.30	14.45	17.34	363.49	10390.30	4.87	12.05	24.55	416.50	3.58	1.47	1.92	4.90	245.00	52.22	0.06	15.32
Average	0.11	2564.21	31.43	4.15	5.75	154.97	1946.79	1.36	4.57	7.79	119.30	1.18	0.41	1.00	0.83	6.97	30.85	0.02	4.29
Median	0.07	1983.92	19.05	2.85	4.82	132.22	1281.18	1.32	4.24	4.88	56.96	0.89	0.16	1.11	0.28	1.93	30.35	0.01	2.59
SE	0.04	592.75	8.46	0.74	0.93	25.99	540.36	0.24	0.62	1.43	30.41	0.18	0.10	0.11	0.30	2.94	2.84	0.01	0.92
Surface water quality standard																			
A						100	1000		100	100	1000	50				10	1000		50
B						800	2000		1000	1000	2000	100				20	4000		100

Note: A: applied to surface water used as source of domestic water supply with appropriate treatments

B: applied to surface water used for purposes other than domestic water supply

3) Total metal concentrations in river water

Even if dissolved metal concentration is the best indicator of environmental metal concentration for toxicity criteria and risk assessment, determination of ambient metal concentrations were originally based on total metal concentrations in unfiltered water. In general, it is seen as desirable to design a water quality standard which, while covering an array of different environmental measures, can be numerically expressed as a single figure; this is consistent with regulatory demand for simple measurements and can be applied in a timely manner (Luoma and Rainbow, 2008). Moreover, since total metals concentrations are easier to detect and are always at least equal to or higher than dissolved concentrations, total concentrations are used when taking a cautionary approach to arising environmental problems. Total metal concentrations are not, however, directly indicative of anthropogenic inputs or their adverse effects.

The Tonle Sap-Bassac Rivers

In the present study, the total metal concentrations of all 19 target elements in the Tonle Sap-Bassac Rivers were compared with drinking water regulations recommended by the US EPA (2009). This was because Cambodia had specified no national standards for metal pollutants in surface water. The Tonle Sap-Bassac system holds a vital role as the main source of water supply production and distribution for Phnom Penh's population. As summarized in Table 2.1-3, all total metal concentrations were lower than national primary drinking water regulations (NPDWRs) recommended by the US EPA (2009). However, Al, Mn, and Fe concentrations were, respectively, approximately 10.4 to 106.6 times, 0.4 to 6.6 times, and 1.1 to 46.1 times higher than national secondary drinking water regulations (NSDWRs). While these metals (Al, Mn, and Fe) lack legally enforceable standards in public water systems, they may cause adverse personal cosmetic effects (such as skin or tooth discoloration), or negative aesthetic effects (such as taste, odor, or color) in drinking water.

The Citarum River

For the Citarum River in Indonesia, of all the regulated elements (Table 2.1-4), Co, As, Se, Cd, and Pb concentrations were well below the national water quality criteria classification (class II) (Indonesian Government Regulation number 82, 2001). River water collected from all sampling sites had Zn concentrations about 3.6 to 17.8 times higher than the criterion value of 5 µg L^{-1}, while Cu concentrations from but few sampling sites were higher than the regulation value of 20 µg L^{-1}.

The lower Chao Phraya River

Only water samples collected in the wet season from two sampling sites, site 7 in an industrial zone and site 8 in a commercial zone, had Mn concentrations higher than the guideline concentration of 1000 µg L^{-1}, which is from Thailand's surface water quality standards (administered by the Pollution Control Department (PCD)) (Thailand Notification of the National Environmental Board, 1994). In the wet season, Mn concentrations at those two sites were about 1109 and 1189 µg L^{-1}, respectively. It was found that Mn concentrations at both sites in the wet season were about 8.7 to 17.2 times higher than samples collected in the dry season. Other elements subject to regulation, including Ni, Cu, Zn, As, Cd, and Pb (Table 2.1-5), were lower than the national standard. Total concentrations of all 19 elements other than Mn (from those two sampling sites) in the wet season were at trace levels. The presence of Al, Fe, and Ti at trace levels in the lower Chao Phraya River was in line with Gaillardet et al. (2003), who concluded that Al, Fe, and Ti are generally present as trace elements in waters since they are less mobile on the Earth's surface.

The Saigon River

Total concentrations of trace metals at all the sampling sites in the Saigon River fell within the "A" surface water quality standards, applicable to surface water in Vietnam used for domestic water supplies (Table 2.1-6), with the exception at several sites for Mn and Fe. Fe concentrations exceeded both the "A" domestic use surface water standards, and the "B" standards covering surface water for other purposes. Al and Fe concentrations in the Saigon River from most sampling sites (except the most upstream Dau Tieng reservoir) can be categorized as minor to major elements on the basis of their total concentrations, which varied from >0.1% to >1%. The results suggested that Saigon River water should be treated prior to use in the water supply.

4) Seasonal variation in dissolved and total metal concentrations
The Tonle Sap-Bassac Rivers

Mann-Whitney U-Test results revealed that there was a significant difference in the dissolved metal concentrations of Cr, Mn, Fe, Co, As, Se, Ba, and Pb ($p \leq 0.05$). The dissolved concentrations of Cr, Mn, and Fe were significantly higher in the wet season than in the dry, while As, Se, Ba, and Pb were significantly higher in the dry season than in the wet season. Luoma and Rainbow (2008) concluded that even though dissolved concentrations are not especially different among river systems, they can be variable over time within a river. However, the results in the present study are in variance with the results reported in Gaillardet et al. (2003) and Luoma and Rainbow (2008). It was reported earlier that the Fe and As concentrations would decease with increasing pH (Gaillardet et al. (2003). This may be caused by several factors, such as the abundance of the elements in the continental crust and their mobility during the weathering and transport process. There is a need for more research on the processes that control the distribution of elements in river waters to better understand this phenomenon.

In the seasonal variation of total metal concentrations, there was a statistically significant difference in the total concentrations of Be, Cd, Tl, Co, V, Ni, Cu, Cr, As, Zn, Ba, Ti, Mn, Pb, Al, and Fe (but not in Mo, Ag, and Se) in the Tonle Sap-Bassac river system ($p \leq 0.05$). In general, the medians of total concentrations were significantly higher in the wet season than in the dry season. The cause may be associated with an intense weathering and erosion over the drainage basin. Several poor communities established along the Tonle Sap-Bassac riverbanks engage in vegetable gardening on fertilized soils. Bird (1987) found high concentrations of Ni, Cu, Fe, Cr, Pb, Cd, Mn, and Zn in the river to be the effect of hydrological factors on the weathering and erosion of land areas. During the wet season, the high waters of the Mekong River reverse the flow of the Tonle Sap River, causing it to flow north into Tonle Sap Lake. Approximately 43.9% of the Mekong River's water is discharged into the Bassac River, one of the main arteries of the Mekong Delta, in the rainy season, and 49% in the dry season (Cenci and Martin, 2004). In the wet season about 6% of the Mekong River discharges into the Tonle Sap River. Trace metal concentrations in dissolved phases during the rainy season were approximately 0.09 $\mu g\ L^{-1}$ Cd, 14 $\mu g\ L^{-1}$ Cu, 8.4 $\mu g\ L^{-1}$ Ni, and 0.50 $\mu g\ L^{-1}$ Cd. Average particulate metal concentrations were 11 $\mu g\ g^{-1}$ As, 9 $\mu g\ g^{-1}$ Co, 29 $\mu g\ g^{-1}$ Cr, 18 $\mu g\ g^{-1}$ Ni, 19 $\mu g\ g^{-1}$ Pb, and 67,000 $\mu g\ g^{-1}$ Al (Cenci and Martin, 2004). Furthermore, the greatest visible difference between pre-storm and storm conditions is the elevated suspended solids loadings associated with high concentrations of metals, especially suspended colloidal Fe (Beckwith et al., 1986; Rule et al., 2006).

The Citarum River

The statistical analysis showed significantly higher Ti, Zn, and Ag concentrations in the wet season than in the dry season ($p \leq 0.05$), while Mn and Co were found to be significantly higher in the dry season than in the wet season ($p \leq 0.05$). Since Ti is a major element in rock and one of the most immobile elements in the Earth's surface (Gaillardet et al., 2003), high wet season Ti concentrations (about 2 times higher than in the dry season) may be due to strong erosion of the river bank. The moderately mobile elements Mn, Co, and V showed different characteristics of distribution from their chemical mobility during erosion. Co, in particular, tends to show decreasing concentrations with increasing pH. However, in this study it was found that its concentrations were higher when pH was higher. This implies the presence of other parameters that control the concentrations of dissolved trace metals in the Citarum River.

For total metal concentrations, Be, Se, Mo, Cd, Ba, Tl, and Pb were 2 to 3 times higher in the dry season than in the wet ($p \leq 0.05$). Only As and Ag were found to be higher in the wet season than in the dry ($p \leq 0.05$). The concentrations of the other remaining elements were not significantly different between the wet and dry seasons ($p > 0.05$). These results indicate the probable diluting effect of rainfall on metal concentrations in the Citarum. Parikesit et al. (2005) also did not find significant differences in Zn and Cu concentrations during the wet and dry seasons along the Citarum. Along the length of the river, several hundred industries, especially textile, chemical, metal, pharmaceutical, and food and beverage producers, discharge their wastewater into the river (Roosmini et al., 2006). Moreover, human activities making use of the heterogeneous landscape are to be found in the Citarum watershed, including tea plantations, cash cropping of vegetables, agroforestry lands, and dryland fields. During the wet season, erosion and transport processes in the upper continental crust can deliver As, one of the more highly mobile elements, into river waters.

The lower Chao Phraya River

Statistical analysis revealed significantly higher dissolved V and Mo concentrations in the dry season than the wet season ($p \leq 0.05$). Concentrations of Cr, Fe, and Cu were significantly higher in the wet season than the dry ($p \leq 0.05$). The abundance of Cu and Cr in the wet season is in accordance with their chemical mobility, as noted in Gaillardet et al. (2003). Classification of trace element mobility in river water categorizes Cr and Cu as moderately mobile elements, with their mobility being 10 to 100 times less than that of Na, with Cu, moreover, forming strong complexes with organic matter (Elbaz-Poulichet et al., 1996).

In terms of the seasonal variation in total metal concentrations, statistical analysis indicated that total Be, Fe, Co, Zn, As, Se, Cd, and Ba concentrations were significantly higher in the wet season than in the dry season ($p \leq 0.05$). Total Al concentration on the other hand was significantly higher in the dry season than in the wet season ($p \leq 0.05$). Al is an important tracer of the aluminosilicate content in the environment and a concomitant background crustal level of metals (Wang et al., 2011); lower Al in the wet season may indicate geologic weathering is not a significant source of Al, or other metals, in the lower Chao Phraya River. Protection of the Chao Phraya basin from degradation and soil erosion was set as a priority by the Thai government; as official measures taken may be showing results. Moreover, it was reported that cultivated land near urban centers along the Chao Phraya River had been converted to residential or industrial use. The urban land use in the Chao Phraya basin covers about 10% of the total area of 159,283 km^2 (http://www.unesco.org/water/wwap/case_studies/chao_phraya/index.shtml). Therefore, the sources of elevated Be, Fe, Co, Zn, As, Se, Cd, and Ba in the lower Chao Phraya River are likely to be anthropogenic. Chanpiwat et al. (2010) found a rising Fe concentration in Bangkok's combined sewer system that receives heavy surface runoff in the wet season. Road runoff may contribute to Fe variation by a factor of 4.4 (Bourcier and Hindin, 1979). However, a direct input of high concentrations of Fe can be found originating from roof sediments and in-pipe sediments (Beckwith et al., 1986). The origin of Ba, Cd, Co, and Zn components of road dust are mainly related to urban activities (Sorme and Lagerkvist, 2002; Duzgoren-Aydin et al., 2006). For instance, in the urban areas of Guangzhou, one of the most rapidly developing cities in China, road dust samples contained Ba (499 mg kg^{-1}), Cd (11.7 mg kg^{-1}), Co (80.1 mg kg^{-1}), Fe (120,600 mg kg^{-1}), and Zn (1,826 mg kg^{-1}). However, the concentrations of As and Cd in ceiling dust were approximately twice the mean concentrations of road dust and gully sediments (Duzgoren-Aydin et al., 2006). In the case of Zn pollution in urban areas, major Zn sources are traffic-related activities including fossil fuel combustion and exhaust emission, and the wear upon brake linings and rubber tires (Sorme and Lagerkvist, 2002; Councell et al., 2004; Gobel et al., 2007). Ba and Zn were commonly added to motor oil sold in Italy and diesel oil in Sweden (Monaci and Bargagli, 1997; Sorme and Lagerkvist, 2002). Sorme and Lagerkvist (2002) reported that about 800-1,400 mg kg^{-1} of Zn were added to the most popular brand of diesel fuel in Sweden. Approximately 40% of Zn released from tires eventually reaches storm water and wastewater treatment systems (Sorme and Lagerkvist, 2002). In addition, corrosion of buildings may result in an enrichment of Cu, Cd, Fe, Pb, and Zn concentrations in urban runoff (DeMiguel et al., 1997; Sorme and Lagerkvist, 2002).

Unlike the metals discussed above (Be, Fe, Co, Zn, As, Se, Cd, and Ba), total concentrations of several of the most common elements in the lithosphere, including Ti, Mn, V, Cr, Ni, Cu, Pb, Mo, Tl, and Ag, when measured in the river water samples collected in the dry and wet seasons, were not significantly different ($p>0.05$).

The Saigon River

The statistical analysis showed non-significant differences ($p>0.05$) in total metal concentrations between the wet and dry seasons, except in both dissolved and total Cu concentrations. The results indicate that the dilution effect usually observed in rivers in the wet season is not applicable to the Saigon River. Important conclusions from Bird (1987) on hydrological factors determining current spatial and temporal patterns of contamination are that the dilution effect in water quality depends on antecedent river flow conditions and river water pH, and that the prevailing dilution processes can occur at any time. However, rainwater's impact on the concentrations of elements cannot be considered merely as simple dilution, because each water parameter follows its own evolution and characteristics (Santarsiero et al., 1996). For the Saigon River, this limited dilution effect might be caused by the short period of Vietnam's rainfall and the flow recharge from the Saigon River to various aquifers in Ho Chi Minh City (HCMC). The aquifer source plays a crucial role in the city's water supply for social development of the city. The rate of groundwater extraction has reached an alarming level, with an exploitation rate of groundwater at about 46% (http://enviroscope.iges.or.jp/modules/envirolib/upload/981/attach/06_chapter3-3hochiminh.pdf). Hence, recharging flows from the Saigon River represent the city's aquifers' water reserve potential. It has been estimated that the water reserve potential of all aquifers in HCMC is about 2,500,000 m^3 day^{-1} (Vo, 2007).

The high concentration of Cu during the wet season found in this study agrees with results of Kikuchi et al. (2009), who studied heavy metal pollution in the river water of Hanoi, Vietnam. They characterized sources of Cu as resuspension of the surface sediment or discharge of wastewater from urban areas. Sunda and Hanson (1979) concluded that Cu is likely in the form of small particles in association with Fe and Mn. A significant portion of the dissolved Cu might come from Cu complexation by dissolved organic matter. Binding Cu by organic ligands should have a marked influence on the biological and geochemical reactivity of Cu in rivers. Remobilization of dissolved Cu can be enhanced during dredging operations. However, Cu can be effectively immobilized from sediments by the presence of high levels of reactive sulfide, which forms insoluble precipitates with Cu (Teasdale et al., 1996). In addition, there are about 30,000 factories in industrial sectors of HCMC, including many large enterprises and light industries in high-technology, electronics, raw materials processing, construction, building materials, and agro-products. Wastewater containing Cu is expected to be discharged from about 45% of all registered industries (such as ferrous metal industries, oil refining, paper milling, and electronics) (http://www.apn-seawed.com/).

5) Determination of the state of metal pollution by normalization technique

The interpretation of environmental metals data is made difficult by the fact that absolute metal concentrations in aquatic environments are influenced by a variety of factors, including both natural factors as well as anthropogenic enrichment. Metals are of particular concern in terms of protecting and rehabilitating aquatic environments, not only because of their potential toxic effects, but also because high metal concentrations can be a signal for the presence of other types of pollution.

However aquatic environment, in particular river water, management efforts generally suffer from several types of deficiencies especially in terms of understanding and dealing with metal pollution. It was summarized by Schropp (1988) that the determination of natural versus unnatural concentrations of metals, as well as the determination of potentially available metals in the water column, is the major aspects of the understanding metal pollution. In order to address both of these aspects, the tool for interpreting metal concentrations (contamination) based on the relationships between naturally occurring metals and a reference element was used.

In this present study, the ratio of dissolved trace metal concentrations to dissolved Fe concentrations were used because of their relatively higher concentrations compared to Al. Moreover, results of linear correlation coefficient analysis of trace metal concentrations to Fe concentrations were higher than those same trace metal concentrations to Al concentrations. The dissolved concentrations were the target of interest because dissolved metal concentrations respond to human inputs (Luoma and Rainbow, 2008). With an exception of Ag, Be and Tl in which their concentrations were not readily available for the normalization technique, eight of fifteen trace metals in river waters from natural river systems exhibited a significant linear correlation with iron (Table 2.1-7). The other seven trace elements including As, Ba, Cr, Cu, Mo, Se, and V were not correlated with iron (Table 2.1-7). Therefore, they were excluded from further analysis.

To identify the metal pollution (enrichment) from natural conditions by application of the regression relationships, results of the analyses of dissolved metal concentrations in urban rivers of SEA were plotted along with the regression line and upper and lower 95% prediction limits from data set of dissolved metals in the natural river systems. Data for each of eight trace metals for which a significant linear relationship was noted are plotted versus Fe in Figure 2.1-2. As clearly shown in Figure 2.1-2, all eight metals including Al, Cd, Co, Mn, Ni, Pb, Ti, and Zn showed their elevated concentrations higher than the natural conditions. Ti was the only trace element that their ratio to Fe concentrations indicated the origin was from natural sources. While the points of the remaining trace elements including Al, Cd, Co, Mn, Ni, Pb, Ti, and Zn fell above the prediction limits. Especially for Co and Zn, in which almost all of the locations sampled in all study areas were seriously contaminated. Sakan et al. (2010) concluded that the greater distance above the prediction limit indicated a greater degree of enrichment caused by particularly anthropogenic activities. Interestingly, Cd showed high enrichment in river water collected from Vietnam. This result of Cd contamination is in good agreement with results of dissolved metal concentrations of Cd in the Saigon River (discussed earlier in Table 2.1-6). The highest and average dissolved Cd concentrations were about 245.0 and 40.5 µg L^{-1}, respectively. The potential source of elevated Cd concentration in the Saigon River is expected to be from anthropogenic sources. This expectation can be convinced by the fact that concentrations of Cd were significantly higher in the dry season than in the wet season. Therefore, high Cd concentrations could not be delivered to the river by either natural sources such as drainage and runoff. While Mn was found to be enriched in most sampling sites of Indonesia Vietnam, and Thailand, as shown in Figure 2.1-2, some points were below the lower prediction limit. In this case, analytical errors should be suspected and examined (Schropp, 1988). Considering a regional basis, Bangkok of Thailand showed the most serious trace metals pollution in urban rivers because concentrations of all trace metals were higher than the prediction bands at most of the sampling sites.

Table 2.1-7: Linear correlation coefficients for metals and iron, according to the relationship: $\log(metal_{\mu g/L}) = a + [\log(Fe_{\mu g/L})]$

Metal	n	r	Slope	Intercept
Aluminum	38	0.58 [a]	1.00	-0.55
Arsenic	20	0.05	-0.16	-0.09
Barium	36	0.02	0.09	1.08
Cadmium	17	0.55 [a]	0.86	-3.39
Cobalt	27	0.60 [a]	0.57	-2.26
Chromium	14	0.11	0.45	-1.23
Copper	26	0.04	0.08	-0.07
Manganese	35	0.34 [a]	0.52	-0.34
Molybdenum	12	0.19	-0.056	0.79
Nickel	30	0.19 [a]	0.35	-0.71
Lead	21	0.47 [a]	0.79	-2.55
Selenium	5	0.07	0.32	-1.68
Titanium	27	0.38 [a]	1.33	-3.44
Vanadium	16	0.11	0.43	-1.37
Zinc	32	0.39 [a]	0.50	-0.84

[a] $p < 0.05$

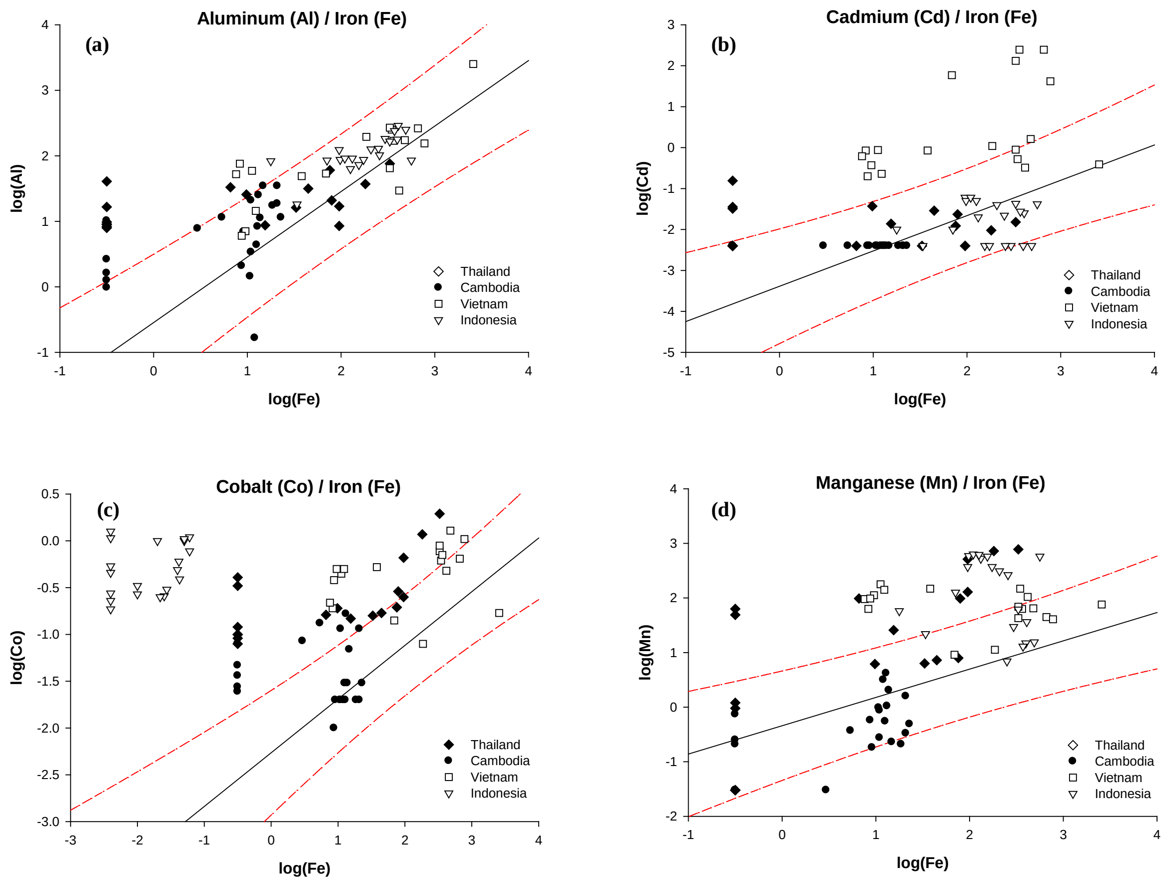

Figure 2.1-2: Logarithmic of aluminum (a), cadmium (b), cobalt (c), and manganese (d) concentrations plotted against iron (Fe). Linear regression lines and ± 95% prediction limits from the undisturbed river waters are superimposed on the data.

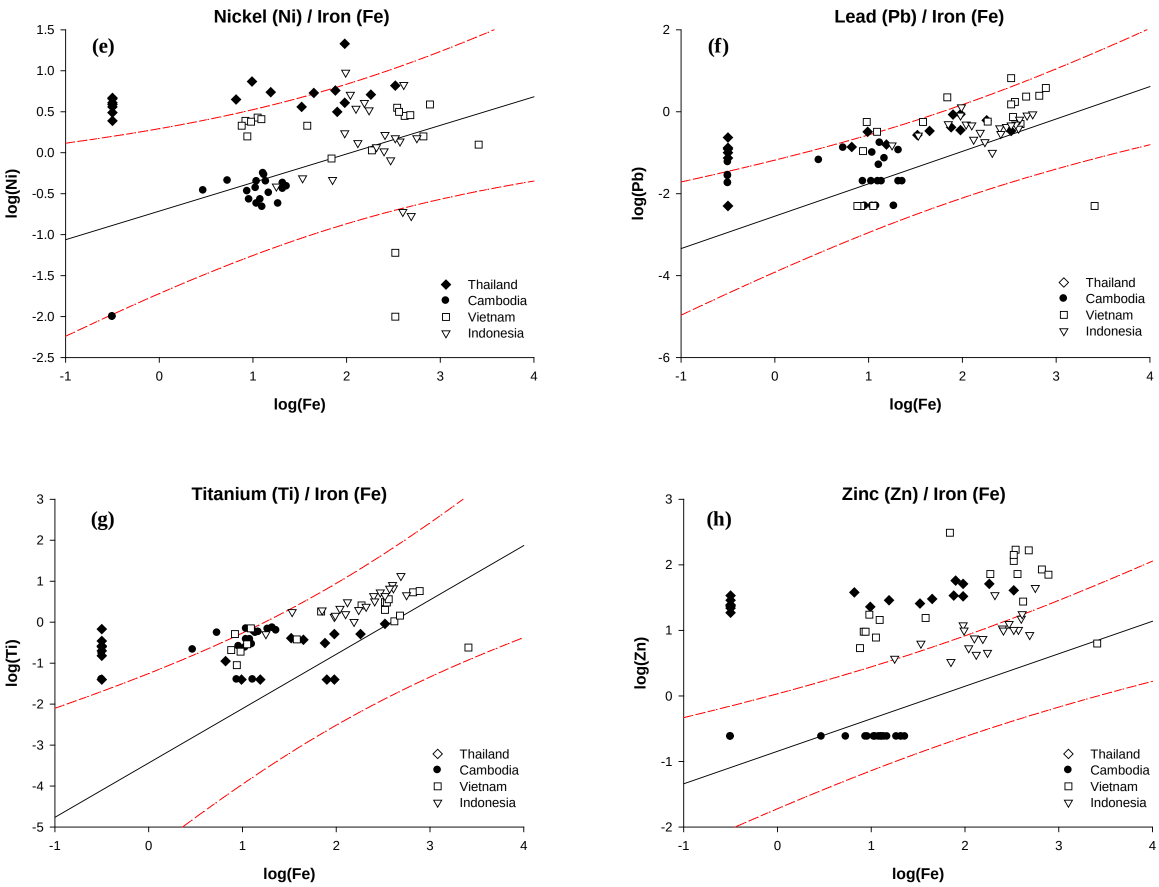

Figure 2.1-2 (continued)**:** Logarithmic of nickel (e), lead (f), titanium (g), and zinc (h) concentrations plotted against iron (Fe). Linear regression lines and ± 95% prediction limits from the undisturbed river waters are superimposed on the data.

6) Quantitative risk evaluation of potential toxicity of metals

Generally, streams and rivers are impaired by a mixture of metals as a result of a manifold of human activities. The potential toxicity of trace metals at chronic concentrations is therefore estimated using cumulative criterion unit (CCU) scores. The CCU score can be calculated based on the ratio of metal concentrations to the US EPA hardness-adjusted criterion continuous concentration (CCC). Water hardness is one of the important factors affecting metal toxicity; as water hardness increases, the bioavailability and toxicity of metals generally decrease.

In this study, both priority (Cd, Cr, Cu, Pb, Ni, Zn, Ag, and As) and non-priority (Al and Fe) metals are of concern for risk assessment. The results of a quantitative risk evaluation (Figure 2.1-3) showed that at all sites of the Tonle Sap-Bassac Rivers, the Citarum, lower Chao Phraya River, and Saigon River, had CCU scores greater than 1. Figure 2.1-3 plainly indicates the chronic, additive, and unsustainable negative effects of metal mixtures in those river systems upon aquatic organisms. The CCU scores of the Tonle Sap-Bassac Rivers, the Citarum, lower Chao Phraya, and Saigon rivers in the dry season varied from 8.1 to 29.5, 134.1 to 433.5, 1.2 to 3.4, and 22.3 to 180.5, respectively. The CCU scores at the same sites on the Tonle Sap-Bassac Rivers and lower Chao Phraya in the wet season were higher than in the dry season by an average multiple of 13.9 and 2.4 times (Figure 2.1-3(a) and 2.1-3(c)), respectively. In contrast, the CCU scores of the Citarum River were generally about 3.1 times higher in the dry season than in the wet season (Figure 2.1-3(b)). The CCU scores for the Saigon River in the wet season were highly varied, from 13.2 to 140.0, and were not usually higher than the CCU scores at the same sampling sites in the wet season (Figure 2.1-3(d)). Interestingly, it was found that the contribution of each metal to the CCU score can change depending on its concentration. Aluminium (Al), a non-priority pollutant, in all study areas contributed about 72% to 94.1% to total CCU scores. The other elements, including Cd, Cr, Cu, Pb, Ni, Zn, As, and Se, generally had relatively lower contributions to total CCU scores (<1% to 19%). Therefore, among all metals Al might contribute the most toxicity to aquatic organisms.

Hirst et al. (2002) observed the responses of diatoms and macroinvertebrates to CCU scores (of 0.8 to 1681) by using correlation, and found significant trends of decline in macroinvertebrate diversity, richness, and total abundance with higher CCU scores. These trends, however, were less pronounced than those of some other water characteristics such as pH, nitrate, Mn, and Cu concentrations. Several diatom species compositions in the Fluvia River of Spain were significantly affected by metal pollution (CCU there ranged from 0.065 to 6.383) and only one diatom specie (*Navicula saprophila*) was found to be tolerant to metal pollution (Guasch et al., 2009). The results of the concentration-response relationships between heavy metals and several macroinvertebrate community structures have shown that macroinvertebrate responses to a mixture of metals Zn, Cu, and Cd, were generally greater than responses to either the mixture of Zn and Cd, or to Zn alone (Clements 2004). However, losses in benthic macroinvertebrate richness, abundance, and function were sometimes found at CCU scores below 1 (Schmidt et al., 2010). Duong et al. (2006) determined only a small number of diatom species known to be tolerant of organic pollution and higher heavy metal loads (dissolved Cd, Pb, Cd, and Zn), and could thrive in the Tolich River of Vietnam. It can be inferred that metal pollution in all the rivers in this study would indeed cause serious ecological risks for aquatic organisms.

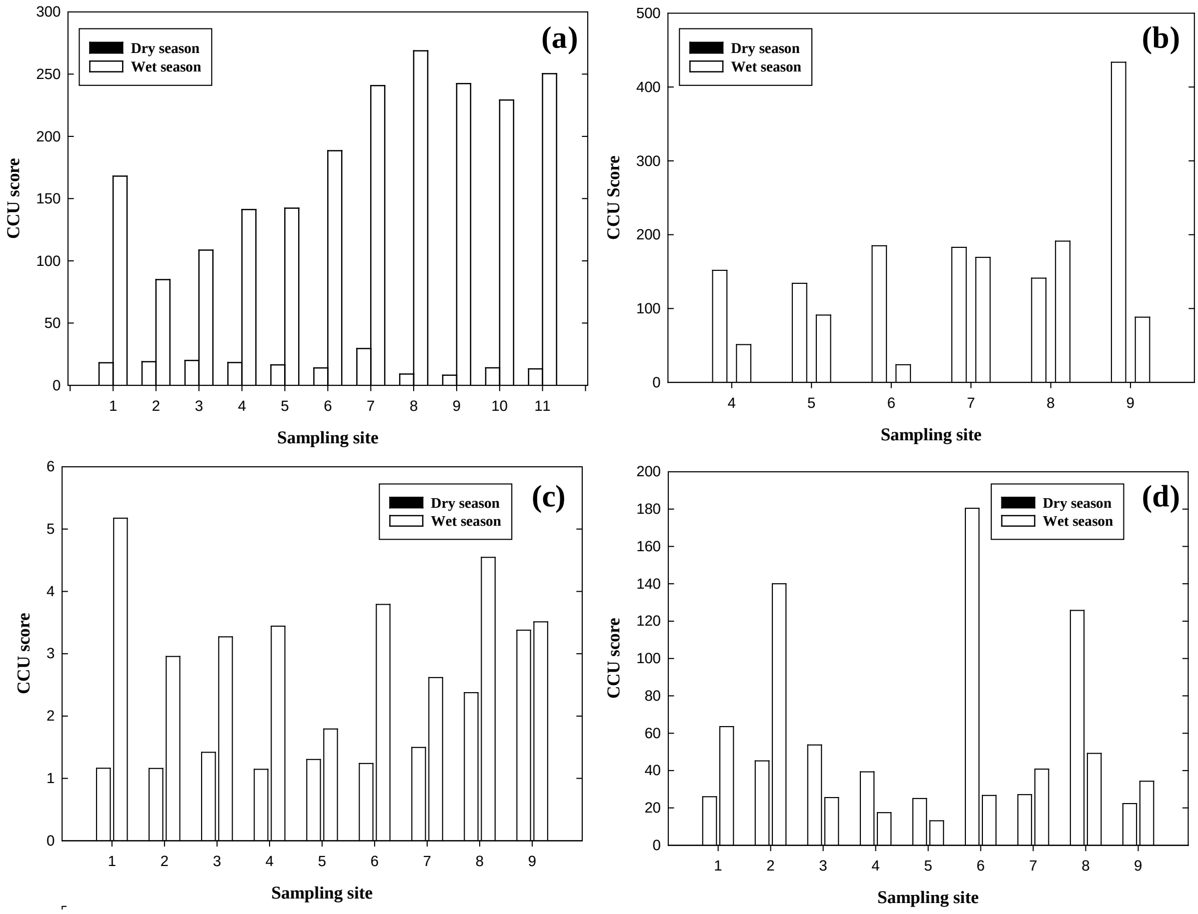

Figure 2.1-3: Quantitative risk evaluation of potential toxicity of metal mixtures in the (a) Tonle Sap-Bassac Rivers, (b) Citarum River, (c) lower Chao Phraya River, and (d) Saigon River.

2.1.4 Conclusions

Although the present study is based on a limited number of samples over huge urban-environment catchment areas, the results give, for the rivers flowing through four Southeast Asian mega-cities, an overview of their pH conditions, dissolved salts content, dissolved and total metals levels, and in addition the seasonal variations in these measurements.

The general water characteristics and metal concentrations in the rivers were found to be site specific. Except for the Saigon River, all the water bodies studied (the Tonle Sap-Bassac Rivers, lower Chao Phraya River, and Citarum River) were in a neutral pH condition. The results of dissolved metal concentrations exceeding the range of background concentrations, as well as the upper 95% prediction limits of the normalization technique, clearly indicated that human activities brought contamination by metal pollution to each river studied here. The total concentrations of Al, Fe, and Mn, which much affect drinking water aesthetics, were found in high concentrations in all four rivers. Overall, the total metal concentrations in the Tonle Sap-Bassac Rivers and the lower Chao Phraya River were significantly higher in the wet season than in the dry season. The elevated metal contents in the wet season likely arrive from such anthropogenic sources as agricultural activities, wastewater treatment systems, and road dust.

Risk evaluation of metal toxicity using CCU clearly indicates the probability of additive and negative effects of metal pollution to aquatic organisms in the study areas. The non-priority pollutant, Al, was found to be the element contributing the highest percentage to total CCU scores. The existing knowledge of trace metals in river waters of SEA is, at present, too incomplete. More research into the processes that control the distribution of trace metals in river water, as well as into the sources of river system metal pollution, should be undertaken to provide us with a sufficient understanding of trace metal behavior in the rivers of SEA.

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2.2 Pathogen Risk Assessment of Urban Water Quality

Prevalence of *Escherichia coli* and Occurrence of Pathogenic Strains in Surface Waters of Four Southeast Asian Cities

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Abstract

In conjunction with sampling for chemical parameters, surface water samples were collected from Vietnam, Indonesia, Cambodia, and Thailand associated with large urban areas in each respective country. Water samples were processed to enumerate *Escherichia coli* and were further characterized using PCR to detect the presence of specific virulence genes. Analyzing the four countries together, the approximate mean log CFU/100 ml for *E. coli* counts in the dry season were log 4.3, while counts in the wet season were log 2.8. Of the 564 *E. coli* isolates screened for the presence of pathogenic genes, 5.3% possessed at least one virulence gene. The most common pathogenic isolates found were Shiga toxin producing strains. These results reinforce the importance of monitoring urban surface waters for fecal contamination and that *E. coli* in these environments may act as opportunistic pathogens. Such survey information is critical in establishing proper water quality parameters and may better predict the impact human pathogens may have on water usage.

2.2.1 Introduction

Surface water not only serves as drinking water sources for metropolitan areas in Southeast Asia, they also serve to facilitate a great deal of economic activity and play an essential part in agriculture. Because of the important role surface waters play in economic and sustainable development of Southeast Asian countries, ensuring sufficient water quality in such bodies of water is critical. Fecal contamination of surface waters is an issue under greater scrutiny from regulatory agencies in both developed, and developing, countries primarily due to multiple incidents where such contamination has been observed in survey studies (US-EPA, 2002, 2005; Santo Domingo, Bambic et al. 2007). The impact on public health is compounded as contamination of irrigation water may also introduce pathogens to the food supply through agricultural products, as exemplified by outbreaks of pathogenic *E. coli* in fresh produce in developed countries (Ackers, Mahon et al. 1998; CDC, 2006). As such, the monitoring of fecal contamination in water sources is a key issue in evaluating water quality.

E. coli is a commensal strain in many mammals and has a broad host range. Although these organisms are part of the normal gut flora, they can act as opportunistic pathogens and may serve as an agent for enteric disease in humans (Nataro and Kaper 1998). Fecal contamination of surface waters commonly serves as a means for disseminating these bacteria in the environment (Simpson, Santo Domingo et al. 2002; Field and Samadpour 2007). As these organisms can persist in the environment (Byappanahalli and Fujioka 1998; Solo-Gabriele, Wolfert et al. 2000), fecal contamination of surface waters is of some interest for gauging overall water quality and its potential impact on public health. Additionally, previous studies have demonstrated that bacterial pathogens may be found in surface waters of Southeast Asian countries (Kobayashi, Khai et al. 2003; PHAN, KHAI et al. 2003; Ha, Kitajima et al. 2008).

Of particular interest to public health are pathogenic *E. coli*, of which several types can induce diarrheagenic infections in humans, with some capable of causing more serious infections such as hemorrhagic colitis (Nataro and Kaper 1998). In the United States it is estimated that pathogenic strains of *E. coli* are responsible for over 200,000 illnesses annually (Mead, Slutsker et al. 1999). Classification of such *E. coli* pathogenic types has been successfully done employing PCR methods (Karch and Meyer 1989; Hornes, Wasteson et al. 1991; Sethabutr, Venkatesan et al. 1993; Tamanai-Shacoori, Jolivet-Gougeon et al. 1994). The focus of this study was to enumerate *E. coli* in urban surface waters within Southeast Asian countries, and further characterize isolates as either, enteroinvasive *E. coli* (EIEC), Shiga toxin-producing *E. coli* (STEC), enterotoxigenic *E. coli* (ETEC), enteropahogenic *E. coli* (EPEC), or enterohemorrhagic *E. coli* (EHEC). Further, enumeration data would be compared to determine if there were any seasonal differences, or that land-use may impact relative numbers of *E. coli* for surface waters in Southeast Asia.

2.2.2. Materials and methods

1) Bacterial Cultures

Both cultures of *E. coli* NCCP 10004 (ETEC) and *E. coli* NCCP 13719 (EIEC) were obtained from commercial stocks supplied by the National Culture Collection for Pathogens, Korea. A cultural isolate of *E. coli* O157:H7 was obtained as generous donation by the Korean Centers for Disease Control and Prevention which served as a control for EPEC, STEC, and EHEC as it contained all of these target virulence genes.

2) Sampling Sites, Land Use Classification, and Sample Collection

Surface water samples were collected in four main rivers that flow through different major Southeast Asian cities. Sampling sites were selected based on their close association with urban metropolitan areas, but also included locations where surface waters were used for irrigation, aquaculture, or were fed agricultural runoff. Bandung (West Java, Indonesia), Bangkok (Thailand), Ho Chi Minh City (Vietnam), and Phnom Penh (Cambodia) were selected due to their high metropolitan populations (over 5 million) and their close association with river bodies within the city boundaries. Between 9 and 20 sites were sampled during a two month period for both the dry and wet season of each respective country in 2010. An additional seasonal sampling event (2 months) was conducted for Thailand during the dry season in 2011. Similar sampling locations (within 20 meters) were maintained as sample points throughout the study over the different seasons.

Land use types for sites were characterized by the apparent runoff sources within 200 m of each location. Sites were either characterized as agricultural or rural (A), urban (U), industrial (I), or mixed (M) being a combination of at least two of the other land use types. Additionally, another land use type was given to water treatment sites. As these sites collected both influent and effluent from water treatment plants, they were deemed control sites (C).

Water samples were collected into sterilized 100 mL polypropylene bottles. Samples were taken below the water surface to minimize floating debris and a head space of roughly 2cm was maintained in each sample bottle. Samples were transported to a laboratory in an improvised ice box (kept under 10°C), and processed within 6-8 hours of collection.

Water samples were sequentially filtered through sterile, 0.45µm, 47 mm filters (Pall Korea Ltd., Seoul, Korea) in 10, 1, and 0.1 ml volumes. If the sample volume was under 10 ml, it was mixed with 10 ml sterile DI water to ensure an even sample distribution over the filter surface. Filters were ascetically transferred to mTEC agar plates (BD Scientific, Maryland, USA) and were incubated at 35 °C for 2 h, and further incubated at 44.5 °C for 22-24 h. Atypical colonies (red to magenta) were counted, the values adjusted to per 100 ml based on the volume sampled, and up to 10 colonies were transferred to plates of MacConkey medium with lactose (BD Scientific, Maryland, USA) for confirmation. The plates were incubated at 35 ± 0.5 °C for 24 h, and isolates were confirmed if expressing light pink to red colony morphology. *E. coli* isolates obtained from Thailand and Vietnam were then transferred to tryptic soy agar (TSA) slants and maintained at 4 °C until shipping and further processing. These countries were selected to ship isolates due to better local facilities for long term storage and access to transportation resources to facilitate rapid shipping of isolates.

Shipped TSA slants from Vietnam and Thailand were further processed in Korea by streaking onto Eosin Methylene Blue agar plates (Lab M Limited, Lancashire, UK) and incubated at 35 °C for 24 hours. Plates which demonstrated typical colony morphology for *E. coli* were transferred into 0.1 ml Luria Betaini freezing medium (Zimmer and Verrinder Gibbins 1997) and incubated with moderate shaking for 24 h at 35 °C. After sufficient incubation, plates were then maintained at -70 °C.

3) *E. coli* DNA Extraction and PCR

E. coli cultures in Luria Betaini freezing medium were thawed and a 50 µl aliquot of the culture was removed, mixed with 50 µl 0.05 M NaOH, and boiled at 95 °C for 15 minutes. This lysate was then used directly as template for PCR.

PCR reactions were run as multiplex or single reactions. To ensure uniformity with the different PCR reactions, a commercial master pre- mix was used (AccuPower HF PCR Mix, Bioneer, Daejeon, Korea). The primers for each reaction are provided in Table 1. Each reaction was prepared using 2 µl template and primers at concentrations of 0.5 µM for AL65/125 (ETEC), 0.25 µM for primer sets $LT_{L/R}$ (ETEC) and ipa III/IV (EIEC), and 0.25 µM of primer sets stx1F/R, stx2F/R (STEC), eaeAF/R (EPEC), and hlyAF/R (EHEC), with DI water added to bring each reaction volume up to 20 µl. In addition to the samples, non-template controls (DI water) and 1 µl template DNA extracted from the control strains were used as negative and positive controls, respectively.

Each reaction was run under previously published conditions (Paton, Paton et al. 1998; Toma, Lu et al. 2003). The exception being for the primer sets AL65/125, as an annealing temperature of 58 °C was used. This higher annealing temperature produced an improved yield of product using template from the control strain (data not shown).

PCR products were analyzed by electrophoresis on 2% agarose gels prepared with ethidium bromide. Digital images were obtained after UV transillumination and the products were compared to both positive control strains and a commercial molecular weight standard. Amplicons of the appropriate size were scored as positive identification of the respective pathogenic *E. coli* gene. Extracted DNA from *E. coli* isolates which demonstrated amplicons indicative of pathogenic genes were subjected to PCR analysis a second time to confirm the initial results.

4) Data Analysis

Means of log *E. coli* counts per 100 ml were analyzed to determine the normality of their distributions. Based on Kolmogorov-Smirnov tests, it was deemed that non-parametric statistical tests (Mann-Whitney and Wilcoxon ranked sum) would be more suitable to interpret differences in the observed means. All statistical analysis was conducted using a commercially available program (SPSS 14.0, SPSS inc., Chicago, USA).

Table 2.2-1: PCR Primer Sets employed in this Study

Primer	Sequence	Gene	Amplicon size (bp)
AL65	TTAATAGCACCCGGTACAAGCAGG	*est*	147
AL125	CCTGACTCTTCAAAAGAGAAAATTAC		
LTL	TCTCTATGTGCATACGGAGC	*elt*	322
LTR	CCATACTGATTGCCGCAAT		
ipaIII	GTTCCTTGACCGCCTTTCCGATACCGTC	*ipaH*	619
ipaIV	GCCGGTCAGCCACCCTCTGAGAGTAC		
stx1F	ATAAATCGCCATTCGTTGACTAC	stx_1	180
stx1R	AGAACGCCCACTGAGATCATC		
stx2F	GGCACTGTCTGAAACTGCTCC	stx_2	255
stx2R	TCGCCAGTTATCTGACATTCTG		
eaeAF	GACCCGGCACAAGCATAAGC	*eaeA*	384
eaeAR	CCACCTGCAGCAACAAGAGG		
hlyAF	GCATCATCAAGCGTACGTTCC	*hlyA*	534
hlyAR	AATGAGCCAAGCTGGTTAAGCT		

Sequences displayed as 5' – 3'

2.2.3 Results

1) Log *E. coli* Counts

Mean log cfu/100 ml *E. coli* counts based on seasonal data are summarized in Table 2.2-2. Sixty eight and eighty nine samples were collected and processed for the wet and dry seasons, respectively, for all four countries. The mean dry season counts were 4.3 log cfu/100 ml, roughly 1.5 log higher than the mean wet season counts of 2.8 log cfu/100 ml for all the land use types (including samples from the control sites). Further, the difference in the means was found to be statistically significant (p = 0.01). When comparing the means based on season the control sites were removed from this set for statistical analysis. This was due to the relative low numbers at these sites that would disproportionately skew the data sets with excessive variance (Figure 2.2-1).

Additional comparisons were made for the mean log *E. coli* counts based on land use. For this analysis, the agricultural/rural sample sites were compared individually to the urban, industrial, and mixed land use sites based on yearly collected data (both wet and dry seasons). The mean log cfu/100 ml values for the land use types ranged from log 1.7 (water treatment control sites) to log 3.9 (mixed land use), with log values for agricultural/rural, urban, and industrial sites being 3.1, 4.1, and 3.8, respectively. There was a statistically significant difference observed comparing the agricultural/rural sites compared to urban sites (p = 0.001) and for industrial sites (p = 0.022), that was not observed when comparing agricultural/rural sites to the mixed land use locations (Table 2.2-2, Figure 2.2-1).

Table 2.2-2: Mean *E. coli* Counts Based on Land Use and Season

Land Use Type	Overall	Dry Season	Wet Season
All Land Use Types	3.61 (±0.14)	4.27 (± 0.14)*	2.76 (± 0.22)
Agricultural/Rural	3.15 (± 0.21)[a]	3.63 (± 0.22)	2.59 (± 0.34)
Urban	4.1 (± 0.19)[b]	4.77 (± 0.16)	3.11 (± 0.33)
Industrial	3.79 (± 0.39)[b]	4.62 (± 0.27)	2.7 (± 0.7)
Mixed Use	3.86 (± 0.32)	3.96 (± 0.5)	3.76 (± 0.5)
Control	1.67 (±0.52)	2.26 (± 0.76)	1.07 (± 0.68)

Counts expressed as log CFU/100 ml
Values in parenthesis are standard error of the mean
* – Mean log cfu/100 ml significantly higher in dry season compared to wet season (p = 0.001)
a,b - Mean log cfu/100 ml for Agricultural/Rural sites significantly lower than Urban (p = 0.001) or Industrial sites (p = 0.022).

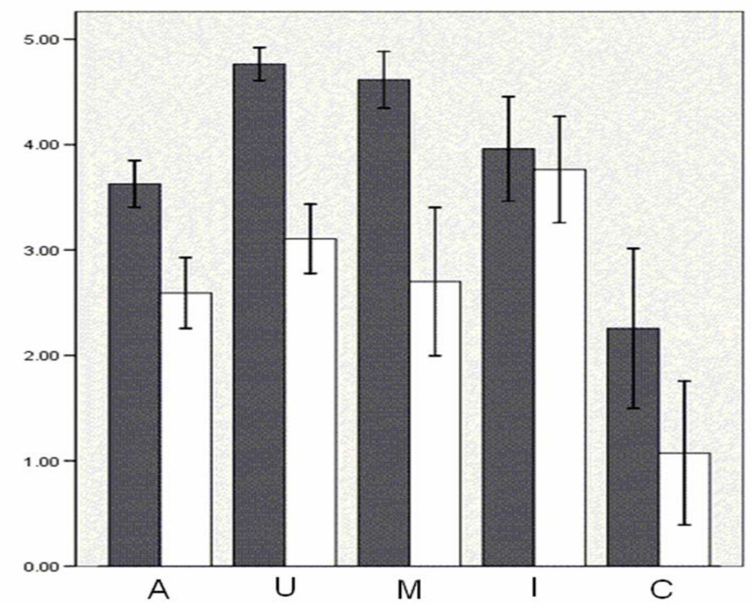

Figure 2.2-1: Mean *E. coli* Values for Land Use Based on Season

Values are mean log CFU/100 ml. Solid bars represent the dry season, open bars represent the wet season. Land use codes are: agricultural or rural (A), urban (U), industrial (I), mixed (M), and control sites (C). Error bars represent standard error of the mean.

2) Observed Pathogenic *E. coli* Types

A total of 564 isolates were processed to determine the presence of virulence genes by PCR. As multiple colonies were taken from the same water sample (up to 10), it was possible that isolates that had similar amplicon genotypes could be clones. To remove this redundancy, additional isolates from the same sampling location and date, which had similar PCR genotypes, were removed from the set. Thus if isolates possessed similar PCR products, this ensured they were collected from different locations, or on different sampling dates (a different month or different season). Less than seven isolates were removed showing similar amplicon profiles for a single sampling event, resulting in 30 strains that possessed pathogenic genes, roughly 5.3% of the total (Figure 2.2-2)

Thirteen of the isolates were deemed as ETEC, possessing *elt* and/or *est* virulence genes. The second most common pathogenic *E. coli* strains observed were STEC strains, which were observed solely in 8 isolates. However other pathogenic *E. coli* types such as EPEC and EHEC also expressed the presence of Shiga-toxin genes (Figure 2.2-3).

Interestingly, the predominant Shiga-toxin gene found was stx_1 (12 isolates), with stx_2 only being found in one strain. Eleven isolates possessed *elt*, with two of the isolates having *est*. The hemolysin gene, *hlyA*, was also relatively common being found in 7 of the 30 strains. Only one of the isolates had *invA*, being considered an EIEC strain. Isolates from both agricultural and urban land use types were observed in roughly the same proportion, being 13 for agriculture/rural sites and 16 for urban sites, with one additional pathogenic strain obtained from an industrial site (Figure 3).

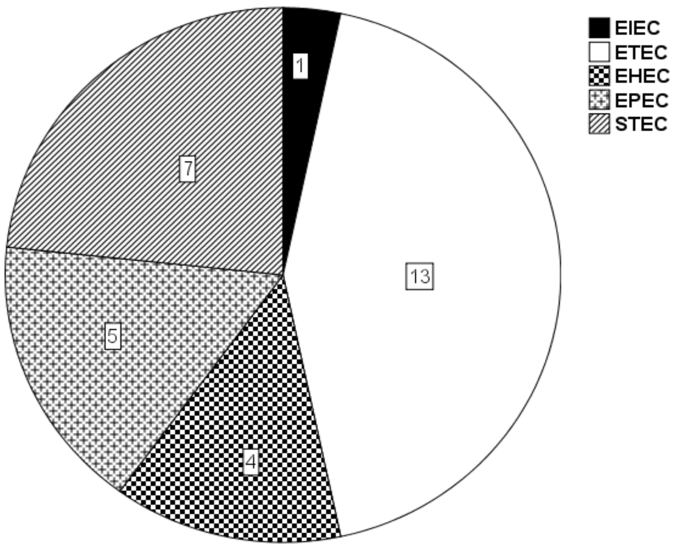

Figure 2.2-2: Observed Pathogenic Genotypes of *E. coli* Isolates

Pathogenic strains designated as either enteroinvasive *E. coli* (EIEC), Shiga toxin-producing *E. coli* (STEC), enterotoxigenic *E. coli* (ETEC), enteropahogenic *E. coli* (EPEC), or enterohemorrhagic *E. coli* (EHEC). Numbers represent the total number of the 30 isolates.

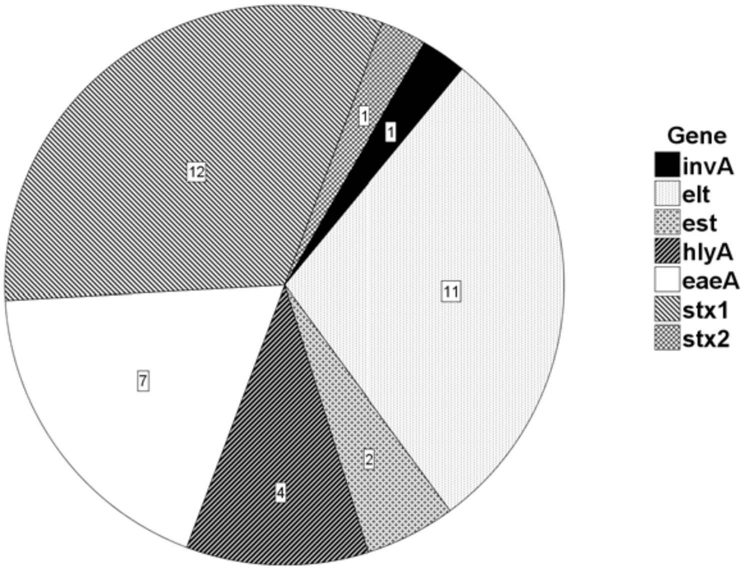

Figure 2.2-3: Pathogenic Genes by PCR of *E. coli* Isolates

Numbers represent the total number observed from all isolates. 16 for urban sites, with one additional pathogenic strain obtained from an industrial site (Figure 2.2-3).

4) Discussion

Compared to proposed standards by the USEPA for Coastal and Great Lakes Recreation Waters (USEPA, 2004), only the mean counts for the dry season exceeded a proposed value of 2.8 log cfu/100 ml, with the mean counts for the wet season being equivalent to this suggested value. Closer examination based on land use and season indicated that for both season types, urban water sources exceeded this value, with some seasonal means exceeding this by more than 1 log (Table 2.2-2). It is important to note that the control sites also had an overall mean of log 1.7 cfu/100 ml, below this recommended value, and this was also observed for the means in both the wet and dry seasons. Interestingly, other studies have also reported seasonal variation of *E. coli* numbers in Southeast Asian surface waters with reduced numbers observed during the wet season (Isobe, Tarao et al. 2004). Additionally, surveys of Southeast Asian agricultural surface waters have reported log cfu/100 ml values similar to what has been observed with this work (Diallo, Anceno et al. 2008; Yajima and Kurokura 2008).

It is important to note that there were significantly higher relative levels of *E. coli* in urban surface waters compared to agricultural/rural waters. Although microbial loads due to fecal runoff of livestock is a likely source of pollution, it is expected that higher density urban areas may have a greater fecal contaminant load in surface waters which receive urban runoff, especially if such wastewater is minimally treated. A survey of treated septage sludge in Vietnamese households reported a mean of 6 log cfu/g of dry weight for *E. coli* indicating that even conventional waste treatment systems may have a potential impact on surface waters if not managed properly (Yen-Phi, Rechenburg et al. 2010). Additionally, surveys of rivers associated in metropolitan areas in Indonesia also have demonstrated similar results to what has been reported here with counts ranging from 2.9-4.8 log cfu/100 ml (Kido, Yustiawati et al. 2009).

Approximately 5.3% of the *E. coli* isolates analyzed demonstrated the presence of pathogenic genes. It is surprising that many of the strains harbored Shiga toxin-producing strains as human sources of this strain are typically associated with *E. coli* O157:H7, however it has been demonstrated that Shiga toxin genes are present in several animal host *E. coli* strains (Nataro and Kaper 1998). It is quite possible that runoff from small livestock operations within urban areas may be a potential source for these strains. However the most common pathogenic *E. coli* type observed was ETEC, determined by the presence of virulence genes, *elt* and/or *est* (Figure 2.2-3). This pathogenic *E. coli* type is typically associated with traveler's diarrhea and fecal contamination of water has been known to be a major factor in its epidemiology (Nataro and Kaper 1998).

One limitation of this study is that the presence of virulence genes is based on the observation of appropriately sized products through gel electrophoresis. No confirmation of the product sequence was attempted, and the authors recognize that sequencing or probe hybridization would be ideal to confirm the amplified products. However as these were isolates initially confirmed through biochemical tests, it was felt that the identification of the strains through differential and selective media, combined with the consequential amplification of virulence genes specific for this organism, sufficient to accept the amplified products were indicative of pathogenic *E. coli* genes, especially as the PCR products were compared to similar sized amplicons from known pathogenic *E. coli* control strains.

From this work, there is an indication that a fair percentage of *E. coli* found in surface waters will harbor pathogenic genes, as 5.3% of the isolates tested possessed virulence genes. However, only a limited number of isolates from each water sample were further processed for PCR analysis. Additionally enteroaggrigative *E. coli*, considered another divergent pathogenic group expressing aggregative adherence to gut epithelia tissue, was not investigated (NATARO, KAPER et al. 1987). This pathogenic phenotype strain was not investigated primarily due to lacking access to a sufficient *E. coli* control strain as a comparative positive control for PCR analysis. Due to these previously stated limitations, the results of this study may provide an incomplete picture to the relative risk of populations that utilize surface waters in Southeast Asia.

None the less it is important to note that even with these limitations pathogenic strains of *E. coli* were observed, and that the reported percentage of 5.3% of isolates expressing virulent genotypes may be a conservative estimate. Given that some mean log counts in urban waters during particular seasons exceeded 4 log cfu/100 ml, the potential for some of those strains being pathogenic may be rather high. Although most pathogenic *E. coli* types require larger infectious doses, combined with these observed high numbers of *E. coli* in surface waters, there is some likelihood that continual exposure to these waters could negatively impact public health. Additionally, O157:H7 is known to have very low infectious doses and EHEC pathogenic types were observed in this study (Cornick and Helgerson 2004), indicating that relative risks to populations that utilize these surface waters for drinking or agriculture practices may be at substantial risk.

Determining potential risk to public health is problematic, however quantitative microbial risk assessment is a tool that policy makers can utilize to better manage fecally contaminated waters and understand its potential impacts on populations (Haas, Rose et al. 1999). Some approaches have utilized models based on reported cases of *E. coli* infections in relation to relative levels of fecal contaminants in surface waters (Soller, Embrey et al. 2010). Having access to empirical count data, combined with surveys of pathogenic types from these samples, may provide a more substantive base of information to create better predictive models. As this study obtained bacterial isolates harboring virulence genes from water samples, their presence highlights the importance of properly monitoring the surface waters in urban areas. This information may also be critical in establishing proper water quality indices, to better predict the impact human pathogens have on water usage. Additionally if these waters are utilized for agricultural use with limited treatment, they may have a greater impact on public health than expected due to potential outbreaks of food-borne diseases.

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2.3 A Review of Urban Water Quality Management: A Comparison Study of Southeast Asian Cities

A Review of Urban Water Quality Management:

A Comparison study of Selected Cities in Southeast Asia

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Abstract

The state of urban water quality many cities in South East Asian presently face are various typical challenges for developing countries — rapidly and uncontrolled population growth, lack of domestic and industrial waste water provision, political will of top policy makers, public awareness, capacity building among others. In addition, appropriate water quality regulation is one of the most difficult challenges in the area of environmental policy as there are always gaps for effective implementation which require more attention from concerned stakeholders. This paper provides an overview on the effectiveness of urban water quality management in selected case in Bandung, Bangkok, Ho Chi Minh and Phnom Penh. Furthermore, SWOT analysis was employed to determine strengths, weakness, opportunities and threats to urban water quality management at the current condition, and to come up with urgent strategies to improve future urban water quality management.

1. Introduction

Sustainable water quality can be interpreted as a continual process to provide safe, clean, and effective distribution of water not only for current populations, but for future generations. The concept of sustainable water includes efforts to maintain the ecosystem by encouraging reuse and reduction the water supply consumption, while still maintaining a role in economic development. Additionally, the future challenges of climate change are factors that need to be considered in the control and monitoring of these critical water supplies[3]. Formally the discussion on sustainable water has been already conducted since 1992, when the United Nations Conference on Environment and Development, following up a concept of the 1987 Brutdtland Commission, which systematically begun to start addressing the need to understand development by incorporating an environmental framework where water was a key point of discussion. The latest hybrid concept, Integrated Water Resources Management, proposes an integration approach to manage all activities over a river basin influencing overall water management (Global Water Partnership 2009).

In many cases, water from flowing rivers through cities have been utilized for long periods of time in various aspects of human activities, and have played an important role as a back bone in economic development. Selected cities Bandung, Bangkok, Ho Chi Minh City and Phnom Penh all have rivers, and all play an important role in the economic and strategic centre of national development for their respective countries. In regard to water quality, however, contamination of water resources is becoming a common event. Such contamination is mainly due to limited domestic waste water

[1] The West Java EMA is the West Java Environmental Management Agency
[2] The West Java Educational and Trainning Agency
[3] Based on outcomes of from a stakeholders discussion which was held in Ho Chi Minh city under the research on Sustainable Urban Water Quality Management

infrastructures and a variety of human activities such as agriculture, urban and industrial development, mining and recreation, all of which can alter the quality of natural waters significantly, and alter future water use potential. Monitoring data shows that water quality of these selected cities still do not meet the required standards, and selected areas have significantly poorer water quality at times. Although various measures to mitigate the negative impacts have been proposed and implemented, these approaches have yet to succeed in improving urban water quality management, where waterways receiving flowing water are highly polluted.

It is a common phenomenon in trans-boundary waters that the majority of agreements regard water quantity issues as the main priority, yet such quality issues are rarely taken up (Bennett, 2000). There are some reasons behind this neglect; lack of tools to quantify pollution, difficulty to predict pollution sources, and a lack of obtaining sufficient direct quantity parameters (Eleftheriadou and Mylopoulos, 2005). Untreated wastewater discharged into rivers causes health hazards to surrounding populations and environmental damages; as cited examples, increased waterborne diseases (Wangsaatmaja, 2004), increased higher morbidity rates in wastewater irrigated villages (Srinivasan and Redy, 2009), and threats to the well being of consumers if contaminated water enters the food chain via wastewater (Seidu et al. 2008). In the other words, water pollution could generate problems along a river and affect a variety of economic losses as well as the quality of human welfare (Dziubinska, 2005).

The most difficult challenge of urban water quality management is the effectiveness of water quality law, and that the policy implemented in place is able to prevent and protect the quality of water resources. This differs from quantity aspects which only consider amount of available water in certain water resources. Water quality aspects have rather more complex mechanisms. Many cases and concepts of urban water quality management are developed based upon the intended purpose or use. Change of water quality is influenced by the substances entering the water, both by natural and anthropogenic processes. In general water quality will vary either from time to time or place to place, depending on seasonal changes, climatic changes, and with the types of soils, rocks and surfaces through which it moves. Eventually the seriousness of water pollution, and its impacts to some extent, has brought increasing health risks to people. In many examples, the main policy tool is made to minimize some emerging problems of urban water quality, so that under larger management oversight, they become more effective both with the relevant targets and with essential infrastructure for urban water quality. The issues of water quality standards adopted under law and regulation are intended to make a compromising path between economic development and ecosystem approaches.

In order to address environmental problems caused by different activities, two approaches could be employed in managing water quality challenges (Nikolau et al, 2011). The first being, policy, command, and control instruments category, which include environmental regulations and laws that regulate related activities producing wastewater, should comply with specific limits and standards. In many examples, this policy tool is made to minimize some emerging problems of urban water quality so that within larger management oversight it becomes more effective. The second approach, market based instruments category, includes economic instruments such as environmental taxes, subsidies and tradable permits as either market-based incentives or disincentives. However, since water in many places is categorized as a public good it typically faces market failure due to the free riding and prisoner's dilemma (Stigliz, 1997; Kaul et al, 1999). Such a dilemma of natural resources depletion, already explained by Hardin (1968), arises from a situation when multiple individuals, acting independently and rationally, consulting their own self-interest, will ultimately deplete a shared limited resource. To date, to address rising problems each government of selected cities have employed some programs and policies to manage the use of water resources. Such governments enact some related regulations and laws such as environmental, water resources management, solid waste disposal, or environmental impact assessment acts, and many standards both in water bodies and effluent, in order to reduce the impacts of the unintended substances entering the water. Ambitious programs, such as Campaign for Clean River, have been promoted however, such programs were not successful due to lack of awareness and support from various water resource stakeholders.

The majority of previous studies in the selected cities focus on examination of technical issues such as land use change and the impacts to community health, developing of some indices as a water resource indicator (i.e. water pollution index and water poverty index), variation in water quality and pollutants loads, or application of mathematical models for modelling water quality. This paper proposes a comprehensive framework means of thinking in order to analyze the most important factors and concerns to assist in designing an overall plan for water quality management of the studied area. The proposed methodological framework based on SWOT analysis aims to find out the strengths, weaknesses, opportunities, and threats that government faces in managing water quality. Finally, urgent strategies are proposed to improve the conditions of selected cities. This paper also provides an overview of urban water quality management policies in Asian cities, the current state and policy intervention applied, and present proposed policy recommendations for urban water quality management based upon the study undertaken in selected cities within Southeast Asia.

2. Literature Review of SWOT Analysis

SWOT analysis is a useful tool for planning and decision making and has been widely applied to almost all area of researches. It first started from business venture applications and expanded into environmental planning and water resources management, where it has been applied to determine what policies should be implemented in the Nile Basin (Belay et al. 2010). An attempt using this tool to develop a sanitation campaign in Maharashtra in India had been done, with the research from this analysis resulting in proposed recommendations to improve total sanitation within this region (Pardeshi, 2008). A very good example how this tool can be applied to examine the ability of municipalities was done in Peru regarding their water and sanitation services (Care, 2006). The SWOT methodology can be used by public policy entities for designing, and stimulating, both an overall plan and specific strategies for green entrepreneurship programs (Nikolau et al., 2011).

On the basis of both internal and external factors, this system proposes to find out four cross-linked development strategies for the evaluation of urban energy systems. Strengths-Weaknesses stand for one energy system possessing the advantages, or disadvantages, of economic factors. Opportunities stand for favourable circumstances and policies of energy saving and emission reduction. Threats stand for low energy efficiency with high carbon and pollutants emission which endanger resources, safety, and cause climate change (Zheng and Fu, 2010). A mixed approach, SWOT-AHP methodology has been tested to identify the needs and perceptions of stakeholders involved with the Nyungwe National Park (NNP) buffer zone in Rwanda concerning the suitability of community-based management and agricultural interests (Masozera et al., 2006), including those of tea plantation and tree farm representatives interfacing with conservation interests (Margles et al. 2010). Furthermore, a new approach to the SWOT method has been proposed combining use of Multiple Criteria Decision Support (MCDS) methods and SWOT analysis. This hybrid method could be applied for increasing and improving the information basis of strategic planning processes. The proposed method not only provides a solid decision support, but also an effective framework for training and learning in strategic decision support efforts (Kangas et al., 2003).

Additionally, some proposed recommendations are established based on developed questionnaires for mining and environmental practices in Greece. It revealed that factors such as lack of funds, bureaucratic requirements, and the low level of employee involvement, were factors playing an important role for mining industry to implement environmental management practices effectively (Nikolau et al. 2010). Performing SWOT tool has also been conducted to map out a recommended strategy to decision makers of eco-tourism industry development in the Qeshm Island, which were focused into providing basic services, exploiting facilities, and improving economic growth based on the on region’s natural and cultural attractions (Jozi and Rezaian, 2010).

The SWOT framework is also used by many scholars as an analytical tool which could be used to categorize significant environmental factors, both internal and external, to different participating organizations (Wheelen and Hunger, 1995; Pickton and Wright, 1998) and then, internal and external factor matrix is created combined with weighting factors to develop an environmental management strategy. Such an analysis on the coastal regions in the Caspian Sea was done using this method and the study also showed that more clear coordination was needed among various organizations involved (Nouri et al., 2008). Additionally this method of an internal and external matrix was also employed to identify internal factors of nuclear energy, when compared with other energy alternatives, and to evaluate the external factors which were against the technological changes in nuclear energy (Lee et al., 2007).

SWOT analysis has been selected to evaluate regional energy planning based on experts' discussion and interaction. The SWOT matrix applied to the energy system of Jae´n province was perceived as a suitable baseline to diagnose current problems and to determine a strategic proposal through interdisciplinary means (Terrados et al., 2007). In a different case, SWOT analysis was adapted to provide a more comprehensive decision-support tool by mapping and developing a set of environmental criteria, in which the method could provide a good basis for assessment and strategy formulation. This paper tried to test the proposed methodology through addressing three main effects namely, urban expansion, land use changes, and passengers and freight flows (Geneletti et al., 2007). While in a different case (but quite similar to the previous work), SWOT analysis was employed to evaluate Environmental Impact Assessment (EIA) practices in India. The article suggested that there were several issues that need to be readdressed after such analysis and it highlighted several constraints, ranging from improper screening and scooping guidelines, to ineffective monitoring and post project evaluation (Paliwal, 2006).

An analysis of influences of implementation of Environmental Management System (EMS) into a local public administration has been explored by the SWOT method. The paper tried to look at the consequences of implementing an EMS within the context of local public administrations both the environmental and economic points of view, particularly regarding the City Council of Ohanes in Almerı´a Spain (Lozano and Valles, 2007). The SWOT tool is also employed when evaluating Project River Recovery in New Zealand. A number of strengths, weaknesses, opportunities, and threats with site visits, interviews with program staff, review of PRR documents, comparisons with international restoration programs are conducted to evaluate restoration programs of the studied area (Caruso, 2006).

SWOT technique could be used for technical issues. One example is given through comparison of four systematic calibration protocols for activated sludge models where existing calibration approaches were critically discussed after using a SWOT analysis (Sin et al., 2005). Additionally, a qualitative investigation using SWOT method has been implemented through community involvement, which qualitative SWOT analysis was performed to construct action plans for municipal solid waste management in order to mobilize and utilize all their resources both from community and government to improve their service (Srivastava et al., 2005).

3. Profile of the Studied Area

This study had focused in four urban areas, the Bandung Metropolitan in Indonesia, Bangkok, Thailand, Ho Chi Minh City, Vietnam, and Phnom Penh, Cambodia. Details of each study area are described in Table 2.3-1.

Table 2.3-1: General comparison of selected cities

Selected Cities	Bandung	Bangkok	Ho Chi Minh	Phnom Penh
Main river	Citarum	Chao Praya	Saigon	Tonle Sap
Total populations (million people)	7.87 (2010)	8.16 (2007)	6.65 (2007)	1.3 (2008)
Area (km^2)	2,340	1,568	2,095	296
Density (person/km^2)	3,336	4,051	3,175	4,571

Source: APN-Seawed Data Base, 2011.

The four chosen cities are rapidly growing urban areas with population densities of 3,000 – 4,000 people per square kilometres. The cities are located in South East Asia which has wet and dry seasons, dominantly influenced by a seasonal shift of wind or commonly known as Tropical Monsoon Climate. The typical climate is humid with abundant precipitation. However each city has different characteristics which are locally influenced. From the point of population and its area, Bandung, Bangkok and Ho Chi Minh City are quite similar. Those three cities can be categorized as a metropolitan city due to their populations exceeding 5 million with areas over 1,500 km^2, while Phnom Penh is categorized as a big city with a population between 1-5 million.

These four cities depend on rivers as a source of water supply. Citarum River located in Metropolitan Bandung is the longest and biggest river in West Java Province and becomes a main feeder for three large dams functioning as a resource for agricultural irrigation, hydropower generated electricity, and as raw water for drinking water. Meanwhile, Tonle Sap as the main river in Phnom Penh, Cambodia, is a unique river and lake system that used for a main water supply for Phnom Penh City. Its flow changes direction twice a year and the water portion that forms a lake expands and shrinks dramatically according to season. Furthermore, Chao Phraya River flows through the Bangkok Metropolitan area dividing it into two zones known as Thonburi and Bangkok. Those areas are well known for canals flowing into the Chao Phraya River. The canals are used for raw water sources and also transportation and irrigation. Lastly, the Saigon River in Ho Chi Minh City (HCMC) which originates from Cambodia is important to Ho Chi Minh City as the main water supply as well as economically, serving as host for the Saigon Port.

The main issue faced by these rivers is water quality contamination from industrial, domestic and the agricultural sector[3]. One of the reasons is because of the absence (Phnom Penh) or lack of capacity of the wastewater infrastructure (Bandung, Bangkok and HCMC) in addition to the specific problems that occur within these cities such as land use change, population growth, urbanization, and current environmental policy.

[3] Based on outcomes of the 2nd Strategic Meeting on Stratetic Policies for Sustainable Urban Water Quality Management in Southeast Asia, Ho Chi Minh, Vietnam, 2010

Figure 2.3-1: Map of the selected cities

Source: http://tattoo20.de.im/keyword/asean

4. Method

The proposed methodological framework is based upon some assumptions, which reflect the important factors affecting the decisions of policy making in addressing, and designing, an overall plan to develop urban water quality management in a sustainable way. Specifically the list of each strategy, including a listing of important external and internal factors, is derived based on the capabilities and expertise of those participating in the strategic planning process.

One limitation of this paper is that it could not employ quantitative analysis (for instance using Analytic Hierarchy Process (AHP) and SWOT) as presented by previous studies (Kuttila et al., 2000; Kangas et al., 2003; Nikolau et al., 2010) when composing the ranking of all proposed strategies. As a result, the proposed strategies in this case essentially use a qualitative approach. Therefore this paper could not perform a quantitative analysis of the outputs being prioritised for SWOT factors as many scholars have been done. Instead we requested that experts, or related stakeholders, justify and do prioritisation of SWOT factors, and gaps which might appear due to bias, statistic, and subjective perception are approached through a situation analysis discussing the existing policy and effectiveness of law and regulations, bringing clarity to issues of urban water quality management.

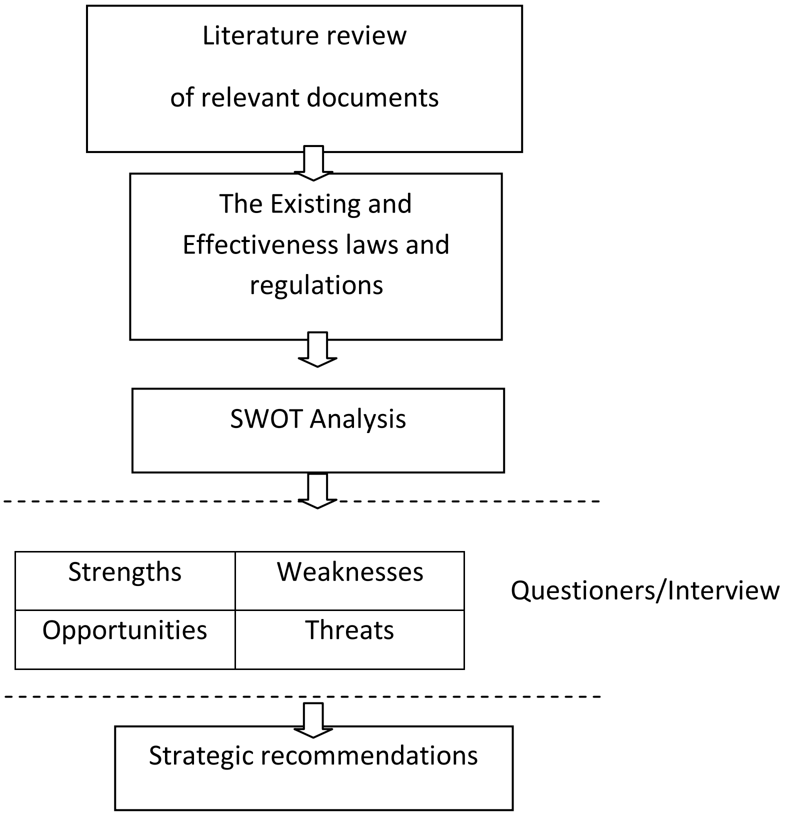

Figure 2.3-2: Methodological framework of the paper

The paper divided SWOT analysis into an internal and external factor evaluation matrix (Saaty, 1987; Weichrich, 1990; Wheelen and Hunger, 1995; Pearce and Robinson, 1988; Pickton and Wright, 1998) and to some extent adopted the method developed by Nouri et al. (2008), in which the total internal factors evaluation (IFE), strengths and weakness, are weighted equally to 100 for each factor. Then, a score is given to each factor. The proposed score range will fall between 1 and 4. A score of 4 indicates high consideration and score 1 indicates low consideration. The next step to develop this matrix is done by multiplying weight and score for each factor. The total sum of this multiplication indicates the priority rank (Rating). The same procedure and similar steps are also applied to the external factors evaluation (opportunities and threats matrix). It is important to note that the strengths may be the advantages based on perception in implementing it, or the direct benefits that arise from an already implemented plan. The weaknesses could be the obstacles that should be avoided in order to respond sufficiently to designed goals. The opportunities indicate the benefits that arise from this plan, while threats show barriers that will have to be overcome for future plans of urban water quality management.

The internal analysis was conducted through evaluating internal factors based on their strengths and weaknesses, while through the same step the external analysis was carried out to evaluate external factors (opportunities and threats predicted to exist if there is a change in the external environments during the implementation of the water quality management). In this paper after those analyses had been finalized, strategy formulations were then developed in order to achieve targets and setting goals. To avoid bias and misinterpretation of developing SWOT factors and the resulting priorities, interviews to concerned stakeholders, specifically experts, were done during the strategic planning process. This crucial step adopted the multiple perspective analysis (Heinonen, 1997; Srivastava et al., 2005). Figure 2.3-2 shows methodological framework employed in this paper.

5. The Existing Policy and its Effectiveness of Water Regulations

To analyze existing policy and its effectiveness, a comparison was made between policy measures in the four selected cities which include regulatory, technical, economy, licensing, and other supporting measures. South East Asia countries have various government systems. Indonesia and Thailand employ autonomy/decentralization, whilst Viet Nam and Cambodia apply a centralized system. The decentralized period in Indonesia began when Act Number 22/1999 on Local Government was issued (then revised several times, the last revision through Act Number 12/2008 and the Government Regulation Number 3/2005). This act handed governing authority (including natural resources management) from the central government to local governments. An implication of this act is that water quality management should be also carried on by each local government.

In general, all four studied cities have national law as a regulatory umbrella in the form of the Environmental Protection and Management Act and/or the Water Resource Management Act. In the case of Bandung, Act Number 32/2009 regarding environmental protection and management is placed as a new umbrella for environment law, replacing Act Number 23/1997. In the context of better water quality management, there are three new points which distinguish it with the previous one. First, environmental license as a basis for other needed licenses. Second, involvement of an environmental platform and strategy in which carrying capacity of water resources must be counted to ensure sustainable development. Third, the paradigm of law principles as a tool of environmental management has totally shifted from administratively employed sanctions or civil means, to criminal penalty.

For HCMC case, at a national level there are some important policy measures for water management to be noted, i.e. Environmental Protection Act (2005) that governs pollution control and protection of seawater, river basins, lakes, canals, ditches, trenches, and groundwater. Another policy remark is stipulated in the Water Resource Act (1998), which particularly administers water quality protection including water pollution prevention from anthropogenic activities such as residential, industrial, farms, slaughter houses, agriculture, and waste disposal. This act also regulates water quality requirements for domestic supply, agriculture, aquaculture, industry and mining activities.

In Thailand's case, it was the 1997 Constitution of the Kingdom of Thailand which has changed in the way the government, its agencies and local communities manage the country's natural resources. The Constitution is intended to direct the government's natural resources and environmental policies, implementation and operation of government projects, and the interpretation of relevant laws and regulations, which gives more power to sub districts in managing natural resources and its use. From the water resource management perspective, the governing system would imply strongly on the policy implementation at various levels of government, including how far the extension of local government authority has in managing water resources in their territory. For instance, in Indonesia, licensing for effluent discharge is issued by local government. The government system would also apply to an institutional framework and coordination between those institutions. This issue will be further discussed later on this section.

In Phnom Penh, The Royal Government of Cambodia has taken action aiming to protect and conserve the valuable usefulness of water and the impact on this environment by other possible activities. Regulation framework on Urban Water Quality in Phnom Penh started in 1993 when the Law on Environmental Protection and Natural Resources Management had been approved to maintain and protect water environment throughout the country in line with socio-economic development in a sustainable manner, under a closed collaboration with key stakeholders. Recently the Law on Water Resources Management has been approved by the National Assembly, of which it should more strongly contribute to the maintenance and protection of the water environment to abide by sustainable, reasonable, and equitable use of water and its resources.

These grand regulations become the direction for other technical regulations below it, including regulation on effluent standards, water quality state, water class, and other technical guidance. In the context of water resource management legislative framework, Bangkok, Bandung, and HCMC already have well established and ample regulations which include standards and technical guidance. Meanwhile, water resource management legislations in Cambodia are mostly in the form of national policy, lacking of technical regulations as applicable guidelines for water quality management measures.

From technical point of view, application of Water Quality Index (WQI) as tool to determine water quality status has been implemented in Bangkok and Bandung. This is important considering WQI is one of the tools that could aid policy makers to judge water quality status, to determine water quality management targets, as well as the strategies to achieve them.

In the Bandung Metropolitan, application of Water Pollution Index was regulated by West Java Governor Regulation No.69 Year 2005 Guideline for Determination of Water Quality Status. This provincial regulation was adopted from national regulation arranged by Ministry of Environment. Water quality status by this regulation could be determined using two legitimate methods: STORET and Pollution Index. Water quality data from regular monitoring was calculated using the two methods to come up with water quality statuses: Heavily Polluted, Moderately Polluted, Lightly Polluted, and Meeting the Water Quality Standard. Of the two methods, Pollution Index proposed by Sumitomo and Nemerow in 1970 is relatively easier to calculate than the STORET method because it enables comparison of the result for each sampling period, and is more flexible in terms of parameters used.

In Bangkok's case, Water Quality Index (WQI) is employed to determine water quality status, while River Pollution Index (RPI) is used for water supply of the Bangkok waterworks. WQI has more parameters considered than RPI which only considers four parameters. It revealed that almost all parameters monitored in 2008 are higher than the average values of the past 10 years. This WQI implies that water quality in the main river and canals are presently highlighted as polluted. Meanwhile, RPI is employed to monitor river conditions throughout the year

In terms of law consequences, there are several levels for violations of environmental law, i.e. administrative, civil, and criminal. In this case, two of the studied cities employ criminal punishment for violation of environmental law (Bandung and Bangkok). Severe consequences for violation of environmental law are expected to be followed by a well established monitoring system, law enforcement system, and improved public awareness. A unique part in the case of Bandung is that the Indonesia Environmental Protection and Management Act No. 32 Year 2009 employs a criminal sanction for violation of environmental law, not only to the parties that conduct environmental pollution or destruction, but also to government officers who fail to perform their monitoring duty.

In economy aspects, water quality management financing schemes could rely on three sources of funds or their combination, government subsidy, private investment, and/or public funding in the form of retribution or service charges. In general, all four studied cities accumulate their funding from a combination of government subsidies, private investment, as well as community service charges. Bangkok is the only city that employs an environmental fund system. An environmental fund seems the promising way to integrate urban water quality management over the encompassing area. By this proposal, financial support will be allocated to facilitate the implementation of a Polluter Pay Principle (PPP) in environmental management. The Environmental Fund Committee manages the fund under supervision of the NEB with the ONEP serving as the Committee Secretariat. However such a mechanism fails to be effectively implemented due to difficulty in accessing the fund, failure to follow up with concrete laws and regulations to support charge implementation, and lack of willingness to charge by local authorities.

Issues faced in water quality management are examples of classic setbacks due to overlapping institutional authorities, tight budgets for adequate monitoring, and lack of proper infrastructure, all in the face of rapid growth of urban areas along with the resulting complexity and pressing environmental burdens associated with such growth. Overlapping institutions in some cases have a close implication to decentralized systems, where there are many institutions with rather similar function yet limited resources to do their work and lack of coordination. A leading sector in water quality management is essential to prompt the implementation of now existing regulations.

Table 2.3-2: Comparative analysis policies and regulation effectiveness of each case

Measures	Important remarks	Selected cities			
		Bandung	Bangkok	Ho Chi Minh	Phnom Penh
1. Regulatory	• Environmental and water resources laws as the regulatory umbrella	✓	✓	✓	✓
	• Devolved powers or desentralizastion	✓	✓		
	• Public participant in preserving, conserving and using natural resources	✓	✓	✓	
	• Criminal penalty	✓			
2. Technical	• Well established standards /technical guidances	✓	✓	✓	
	• Employ water pollution index as a basis for developing water quality policies	✓	✓		
3. Economic	• Government subsidy	✓	✓	✓	✓
	• Investment for sanitation infrastructure	✓	✓	✓	✓
	• Public Private Partnerships	✓	✓	✓	
	• Environmental fund		✓		
	• Waste water charge	✓	✓	✓	
4. License	• It has been transffered to local government	✓			
5. Additional	• Promoting green technology	✓	✓	✓	✓
	• Capacity building	✓	✓	✓	✓
	• Community based participation	✓	✓	✓	
	• Information disclosure	✓	✓	✓	

6. Results and Discussion

Strengths, weaknesses, opportunities and threats (SWOT) analysis was applied in order to evaluate urban water quality. Table 2.3-3 shows internal factors influencing urban water quality management differs considerably from city to city. In this discussion, it is impossible to make uniform strategies since they all have a different background with respect to localities of each case. Thus, the developed strategies to improve their urban water quality management and the sequence of detail actions will vary dramatically from one case to another, and will substantively be different for each country.

Moreover, the priority of strategic identification was evaluated based on expert's interviews to prioritise the most important factors considered that would significantly impact urban water quality management for each selected case. The list of internal and external factors were investigated, and then ranked according to interviews conducted by concerned stakeholders, specifically experts. The priority of factors was composed in an orderly fashion, in which total weight and score performed were calculated through the average value of each expert's evaluation. Such quantitative analysis was then employed to rank which were the most important influencing factors, using an internal and external analysis summary. Focusing once more on developing proposed strategies, only 2 out of the 4 SWOT factors were considered for further steps. The process of selection could be looked at by internal and external factors analysis summaries of each case (see annexes 1 – 4 for detail process). Table 2.3-3 shows the internal factors analysis investigated as the strengths and weaknesses of the water quality management for each of the selected cities.

Table 2.3-3: Internal factors influencing urban water quality management

Cities	Strengths	Weaknesses
Bandung	• Leader's commitment • Available laws	• Lack of coordination • Lack of law enforcement
Bangkok	• Striving for Green Bangkok • Well Developed Wastewater Treatment Plan	• Fragmented Responsibility • Lacking Progress of Mega Project
Ho Chi Minh	• Concern and ready cooperation • Water resources are diverse and abundant	• Unclear policies • Lack of water quality monitoring
Phnom Penh City	• Strong Government Commitment • Well Managed Plan/Framework	• Lack of law Enforcement • Insufficient Budget of State Sector

Sources: SWOT analysis of each selected cities, unpublished, 2011.

Internal Analysis Factor Summary:

Strengths: As presented at Column 2, it should be noted that urban water quality management, in some cases, were linked with political will of leaders. A good example is given by the cases of Bandung and Phnom Penh. It is realized that since no leader's commitment are in place, it is difficult to implement programs related to improvement of water quality. This might be related to the previous experiences that all efforts to improve urban water quality management involve support of a leader's commitment. The other strength of Bandung case is available laws and regulations as the most important factor to influence the decision making process. In Bangkok's case, there is a master plan targeting twenty central wastewater treatment plants which will be installed by 2020. It reveals that the commitment to expand sanitation coverage becomes an entry point for improving water quality management of Bangkok Metropolitan Area. In line with the goals of a sustainable city, primarily they are striving to achieve a "green Bangkok in the horizon 2020" perceived as a strength in order to improve its urban water quality management. There are two strengths proposed by Ho Chi Minh City, both of which demonstrate concern and willingness to cooperation at different management levels, and that water resources are diverse and abundant.

Weaknesses: Two of the three selected cases, Bandung and Phnom Penh, present that law enforcement is the most prominent weaknesses within urban water quality management. One of weakness of the Bangkok and Phnom Penh cases is lack of funds in constructing mega projects on wastewater treatment plants (doing so would require a tremendous amount of funding sources). In Ho Chi Minh City, there exists a body of rigorous and well comprehensive set of laws and regulations, however actual polices are ineffective in how they are implemented, as such policies are unclear, vague, or in some cases unsuitable. Such situations are closely related to ineffective coordination of stakeholders and overlapping institutions due to having similar functions and responsibilities (something observed in all the cases). The other weakness is lack of water quality monitoring and infrastructure, in particular at upstream areas. For the case of Phnom Penh, it is perceived that lack of a sufficient government budget is one of the most important weaknesses impeding the state of water quality management, and likely cannot improved significantly until this deficiency is addressed.

External Analysis Factor Summary:

The external analysis factors considered as opportunities and treats of urban water quality management for selected cities are summarized in Table 2.3-4.

Table 2.3-4: External factors influencing urban water quality management

Cities	Opportunities	Threats
Bandung	• Support from national & international institutions • National strategic river	• Population pressure • Lack of infrastructures
Bangkok	• Good national strategic plan • Collaborative cooperation	• Economical and political crisis • Urbanization
Ho Chi Minh	• Capacity and collaboration on river basin • Enhanced community awareness	• Climate changes • Poor performance of scientific engineering and infrastructures
Phnom Penh City	• Potential supporting fund of donor • Support from many institutions	• Insufficient capacity/resources • Public Participation and Awareness

Sources: SWOT analysis of each selected cities, unpublished, 2011.

Opportunities: A grouping of the opportunities, and the level of importance of each selected cities, is presented in Table 2.3-4. In general government commitment at all levels appears for each case, especially for Bandung since it has already been appointed as a national strategic river, thus national and international support will likely be easily obtained. Such a situation brings more attention to this issue, and until 2025 there has been a strong commitment to fund, and blueprints of an agreement have been made to effectively manage this river system. Bangkok's case proposes another opportunity in the importance of urban water quality management and establishing alliances on water quality research effort. In Phnom Penh's case, regional and international cooperation are beneficial towards maintaining, protecting, and conserving the environment and sustainable natural resources of the Mekong River, including its tributaries from various development activities

Threats: A short analysis indicating the threats of selected cities are summarized in Table 2.3-4. External factors of threats influencing urban water quality management for Bandung were population pressures and lack of sufficient infrastructure. Population growth is totally beyond control of respective urban water quality management, but it influences indirectly to other activities related to river water. As explained earlier, growing population triggers change of land use from deforestation due to urban settlement, to expansion of cultivation areas from farming, all of which leads to being a driving force for natural pollutants. The other threat is results of climate change which influences the pattern of rainfall events, bringing changes to the complexity of quantitative-qualitative aspects of the river. In Bangkok perception of economic and political crisis serves as another factor threatening urban water quality management. Ho Chi Minh City notes that quality of water sources is more degraded through exploitation, and wasteful use, of water sources as being prominent external factors treating water quality management. In Phnom Penh's case, external factors to treating urban water quality is likely due to insufficient capacity of concerned stakeholders, and lack of public awareness, so concepts of protection and conservation of the water environment should be taken into account and applied in parallel with any development process.

In this paper, the findings presented as SWOT factors in the above section were further grouped and used in a separate matrix of each selected case, to derive some proposed strategies in order to improve water quality management. It is important to note that the following lists do not represent prioritised strategies in an orderly fashion. Rather, strategies were derived from SWOT profiles of selected cities divided into Strengths-Opportunities (SO), Weaknesses-Opportunities (WO), Strengths-Threats (ST) and Weaknesses-Threats (WT). The proposed strategies for each metropolitan area are as follows:

Bandung case, Indonesia:

- (SO_1) Using the current top management to synergize stakeholders support
- (SO_2) Optimising institutional support and the status of river by using the current top management support
- (SO_3) Using the experiences and facilities of international institutions
- (SO_4) Enhancing national and international fund to implement water programs
- (WO_1) Improving stakeholders coordination mechanism at implementation level
- (WO_2) Improving inter sector coordination on government policy implementation
- (WO_3) Improving law enforcement through integrated law enforcement team in strategic river basin
- (WO_4) Reviewing the existing laws and regulations on water quality and other related laws
- (ST_1) Using top management for population control policy
- (ST_2) Establishing concerned laws on more clear governing authority
- (ST_3) Endorsing the related cities located in Bandung Metropolitan to control their population growth
- (ST_4) Increasing local government budget for providing infrastructures
- (WT_1) Improving integrated team coordination to control population pressure
- (WT_2) Arranging incentive and disincentive regulation to control population
- (WT_3) Using local government authority
- (WT_4) Establishing an integrated team to support law enforcement mechanism

Bangkok case, Thailand:

- (SO_1) Implementing additional measures and developing wastewater treatment technology for resident and business buildings.
- (SO_2) Cooperate among all parties concerned, in public/private/people to conserve and rehabilitate river and canals in Bangkok.
- (SO_3) Expand wastewater treatment service area for increasing percentage of treated water.
- (SO_4) Develop research project on sewerage system , WWT technology and water quality management
- (WO_1) Improve stakeholders coordination at improvement level
- (WO_2) Improve law and regulations by decreasing the number of institutions involved and increasing cooperation among institutions.
- (WO_3) Establish monitoring database and network.
- (WO_4) Collaborative with financial institute for mega project
- (ST_1) Install small-scaled on wastewater treatment in community.
- (ST_2) Collaborate with government sectors, private sectors, and general public on water quality management.
- (ST_3) Develop environmental friendly design for wastewater treatment project through community participate.

- (ST_4) Improve sewerage collection system
- (WT_1) Strictly measures and enforcement of laws and regulation.
- (WT_2) Pull and push methods of public participation and awareness.
- (WT_3) Wastewater tariff will be collected together with water supply bill.
- (WT_4) Set up land use zoning particularly in suburban area

Ho Chi Minh case, Vietnam:

- Increase the cooperation on river basin management from central to local levels
- Promulgate specific policies on water resources management which are both suitable for local sub-basin development and for the national goals
- Complete and enhance inter-cooperation on water -quality monitoring in/cross the basins
- Approach and apply the technological solutions for rational use and protection of water resources
- Disclosure and disseminate information on existing management of water quality
- Share the water resources among water users along the basin
- Apply the results of water-quality monitoring on identifying the sensitive and vulnerable areas to climate changes and increase the supervision and monitoring in those areas
- Coordinate on management between levels to adapt to impacts of climate changes
- Issue new policies on water tariff which encourage water saving and protecting water resources
- Increase the application of model science and technology on water quality monitoring
- Promulgate the incentive policies and investments on scientific research on water quality management; invest in equipments, improve infrastructure for protecting and improving water quality
- Minimize the impacts of climate changes on water resources
- Encourage the community participation on water -quality monitoring and supervising
- Add new policies on water quality management in association with scenarios of climate changes
- Stimulate, encourage and support on using different water resources
- Building capacity on advanced technology implementation on water quality management for managers

Phnom Penh case, Cambodia:

- (SO1) Increase funding from donor by using strong government commitment
- (SO_2) Use top management commitment to maximize international institution and NGO participation
- (SO_3) Use well management plan/framework to increase funding from donor to manage river water quality
- (SO_4) Enhance international institution and NGO participation by well management plan/framework
- (WO_1) Improve monitoring activities at local and ministry level
- (WO_2) Improve law enforcement through stakeholder participation
- (WO_3) Improve the amount of budget for monitoring and law enforcement
- (WO_4) Improve budgeting by participating from stakeholders
- (ST_1) Use top level commitment for building capacity of government staffs
- (ST_2) Increase public participation and awareness in water quality monitoring using top commitment
- (ST_3) Improve research capacity of government staffs in river water quality management and control
- (ST_4) Increase public participation and awareness using well management plan/framework
- (WT_1) Develop capacity in water quality monitoring by strict law enforcement

- (WT_2) Use strict law enforcement for public participation and improving awareness
- (WT_3) Strict monitoring for violation of river water quality management policy
- (WT_4) Use strict law enforcement to control solid and liquid waste from commercial and residential sector

7. Conclusions

In many instances, this tool provides an overview of strengths, weaknesses, opportunities, and threats to urban water resources and enables public policy makers to prepare sufficient natural resource management policies. Although most of the selected cases have rigorous laws and regulations, as well as technical guidance in place, the water quality state of main rivers still will undergo pressures and problems that will result in almost all monitored parameters failing to meet the targeted pollution indices. This paper shows that urban water quality management of selected cities, in some cases cannot be generalized as one uniform state. Different situations obviously influence the complexity of management of each case study, as a result, proposed strategies will vary from case to case.

The following strategies are proposed in terms of managing water quality throughout the studied areas. Straightforward diagnosis of each proposed strategies was examined through efforts to explore the ways and means of converting possible threats into opportunities, and changing weaknesses into strengths, resulting in strategic plans of action developed for better water quality management. Accordingly, this paper proposes strategies derived on diagnosis of SWOT factors for improvement of water quality management in selected cities, namely, 5 strategies related to top management support, 19 strategies concerning policy and regulation, 6 strategies concerning international cooperation, 5 strategies of budgeting policy, 11 strategies on stakeholder coordination and participation, 2 strategies on capacity building, 5 strategies related to research, 5 strategies on providing infrastructure, and 6 main strategies on law enforcement

The critical point which should be addressed in implementing urban water quality management is providing a policy which serves as a foundation for further planned steps. It is important to note that urban water quality management is so closely related to ongoing activities, both directly and indirectly, that some aspects such as integrated land use planning, domestic and industrial activities, solid waste management, hazardous waste handling, and concerned stakeholders involvement are vital in establishing effective policies. This measure should incorporate some considerable thought such as establishing targets for water quality status, making priority of areas which should be managed, establishing a sufficient network for water quality monitoring, enacting appropriate laws and regulations, and include considering an equivalent perspective not only to water quality, but also aspects of water quantity. Nevertheless, all cannot be conducted in place without sufficient trained human resources at all levels.

Fact finding of the selected cases show that commitment of top management is a key point to optimising stakeholder involvement, in order to set up policy planning and obtaining greater public participation. This looks likely a pre-requirement for implementing whatever policy planning the selected cases have. In the other words, the more commitment present from top management, the more effective urban water quality can be increased. As seen in Bandung, the effectiveness of laws and regulation enforcement considerably rely on this aspect of support.

The second fact reveals that urban water pollution mostly comes from improper wastewater discharge, both domestic and industrial. Hardly do all the selected cases provide a significant number of wastewater treatment resources. Because of lack of wastewater infrastructure, urban water quality of the selected cities scarcely reaches a good state. Moreover, this condition will lead not only to the threat of surface waters, but also to the decrease of groundwater quality. By reflecting on the above situation, it is highly recommended that improving coverage of wastewater infrastructure serve as a main strategy to increase urban water quality of all the selected cases. This strategy cannot serve solely, but should be also supported by additional measures such as finding sufficient funds, and fostering public participation and community involvement to establish off site systems for those who do not have access to centralized wastewater treatment.

The third important factor shows that capacity building and strengthening institutions is a general strategy which can be employed by many stakeholders at nearly all levels. The lack of human resources is a common barrier observed within all selected cases. Capacity building through improving human resources dealing with water quality issues is an inevitable recommendation of this paper. Capacity building should be directed towards partners at the national, provincial, and community levels. Not only should they incorporate forming a dialog with policy makers at the national level (parliament, legislators, and water authorities), but also with educational institutes such as universities (including primary and secondary schools), and with NGOs and other community groups. Another key partner in capacity building should be with economic development policy makers and financial industry leaders. Additionally, areas in capacity building should be directed towards education programs to further water resource management goals (water use efficiency, water quality awareness, etc.).

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Annex 2.3-1: Internal and External factors analysis summary of Bandung Case

No	Internal Strategic Factors	Weight	Score	Rating	Priority	No	External Strategic Factors	Weight	Score	Rating	Priority
	Strengths						Opportunities				
1	Available laws	15	3	45	II	1	National strategic river	15	3	45	II
2	Leader's commitment	15	4	60	I	2	Support from many institutions	15	4	60	I
3	Research concerned	10	4	40	III	3	Private public partnerships	10	4	40	III
4	Decentralization	10	3	30	IV	4	Collaborative exchange	10	3	45	IV
	Weaknesses						Threats				
1	Overlapping laws	10	4	40	III	1	Population pressure	15	4	60	I
2	Lack of coordination	15	4	60	I	2	Infrastructures	15	3	45	II
3	Lack of data base and monitoring	10	3	30	IV	3	Public awareness	10	4	40	III
4	Lack of law enforcement	15	3	45	II	4	Climate change	10	3	30	IV
		100						100			

Source: SWOT analysis of Bandung case, Indonesia, 2011, unpublished.

Annex 2.3-2: Internal and External factors analysis summary of Bangkok Case

No	Internal Strategic Factors	Weight	Score	Rating	Priority	No	External Strategic Factors	Weight	Score	Rating	Priority
	Strengths						Opportunities				
1	Well Developed Wastewater Treatment Plan	15	3,36	50	II	1	National strategic plan on sustainable conservative and	15	3,55	53	I
2	Striving for Green Bangkok	15	3,45	52	I	2	Collaborate cooperation	15	3,45	52	II
3	The Bangkok Agenda and Development Plan	10	3,00	30	III	3	Public awareness	10	3,18	32	III
4	World's Best Award 2010	10	3,00	30	IV	4	Available Technology	10	3,09	31	IV
	Weaknesses						Threats				
1	The sewerage combined system	10	3,36	34	III	1	Lack of clear policy and fail to enforce with law to control	10	3,55	35	III
2	Fragmented Responsibility	15	3,36	50	I	2	Economical and political crisis	20	3,55	71	I
3	Lacking Progress of Mega Project	15	3,27	49	II	3	Urbanization	15	3,55	53	II
4	Inadequate capabilities of responsible agencies	10	3,09	31	IV	4	Climate Change	5	2,27	11	IV

Source: SWOT analysis of Bangkok case, Thailand, 2011, unpublished.

Annex 2.3-3: Internal and External factors analysis summary of Ho Chi Minh City Case

No	Internal Strategic Factors	Weight	Score	Rating	Priority	No	External Strategic Factors	Weight	Score	Rating	Priority
	Strengths						Opportunities				
1	Water resources are diverse and abundant	15	3	45	2	1	Attract for investment	10	1	10	4
2	Concern and ready cooperation of different management levels	15	4	60	1	2	Restrict groundwater exploitation	10	2	20	3
3	Legislative framework and institution arrangement are adequate and reasonable	10	2	20	3	3	Enhanced community awareness	15	3	45	2
4	Water quality management organization has deep experience	10	1	10	4	4	Capacity and collaboration on river basin management were more and more concerned	15	4	60	1
	Weaknesses						Threats				
1	Lack of mechanism and policies for water quality management and less flexible	15	15	4	60	1	Climate changes	15	4	60	1
2	Overlap of responsibility and lack of cooperation among agencies	10	10	2	20	3	Industrial development	10	2	20	3
3	Water quality monitoring at upstream are not	15	15	3	45	2	Urbanization	10	1	10	4

	enough and weak										
4	Not stimulate the municipal participation on water resources management	10	10	1	10	4	Poor performance of scientific engineering and infrastructures	15	3	45	2
		100						100			

Source: SWOT analysis of Ho Chi Minh case, Vietnam, 2011, unpublished.

Annex 2.3-4: Internal and External factors analysis summary of Phnom Penh Case

No	Internal Strategic Factors	Weight	Score	Rating	Priority	No	External Strategic Factors	Weight	Score	Rating	Priority
	Strengths						Opportunities				
1	Strong Government Commitment	15	4	60	I	1	Potential Supporting Fund of Donor	15	4	60	I
2	Well Managed Plan/Framework	15	3	45	II	2	River Water Quality Standard for Cambodia	10	3	30	IV
3	Decentralization Policy	10	3	30	IV	3	International Institution and NGO Participation	15	3	45	II
4	Multi-Response of Co-Ministries	10	4	40	III	4	Potential Development Plans/Projects	10	4	40	III
	Weaknesses						Threats				
1	Lack of Coordinating Mechanism	10	4	40	III	1	Population Pressure	15	3	45	II
2	Non-Sufficient Budget of State Sector	15	3	45	II	2	Insufficient Capacity/Resource	15	4	60	I
3	Lack of Monitoring/Enforcement	15	4	60	I	3	Public Participation and Awareness	10	4	40	II
4	Absence of Comprehensive Legislation	10	3	30	IV	4	Climate Change	10	3	30	IV
		100						100			

Annex 2.3-5: Proposed strategies of urban water quality management in Metropolitan Bandung

INTERNAL FACTORS / EXTERNAL FACTORS	**Strengths** 1. Leader's commitments 2. Available laws	**Weaknesses** 1. Lack of coordination 2. Lack of law enforcement
Opportunities	**SO Strategies**	**WO Strategies**
1. Support from national and international institutions 2. National strategic river/watershed	– Using the current top management to synergize stakeholders support – Optimising institutional support and the status of river by using the current top management support – Using the experiences and facilities of international institutions – Enhancing national and international fund to implement water programs	– Improving stakeholders coordination mechanism at implementation level – Improving inter sector coordination on government policy implementation – Improving law enforcement through integrated law enforcement team in strategic river basin – Reviewing the existing laws and regulations on water quality and other related laws
Threats	**ST Strategies**	**WT Strategies**
1. Population pressure 2. Lack of infrastructures	– Using top management for population control policy – Establishing concerned laws on more clear governing authority – Endorsing the related cities located in Bandung Metropolitan to control their population growth – Increasing local government budget for providing infrastructures	– Improving integrated team coordination to control population pressure – Arranging incentive and disincentive regulation to control population – Using local government authority – Establishing an integrated team to support law enforcement mechanism

Source: SWOT analysis of Bandung case, Indonesia, 2011, unpublished.

Annex 2.3-6: Proposed strategies of urban water quality management in Metropolitan Bangkok

INTERNAL FACTORS / EXTERNAL FACTORS	**Strengths** 1. Striving for Green Bangkok 2. Well Developed Wastewater Treatment Plan	**Weaknesses** 1. Fragmented Responsibility 2. Lacking Progress of Mega Project
Opportunities	**SO Strategies**	**WO Strategies**
1. National strategic plan 2. Collaborative exchange	– Implementing additional measures and developing wastewater treatment technology for resident and business buildings. – Cooperate among all parties concerned, in public/private/people to conserve and rehabilitate river and canals in Bangkok. – Expand wastewater treatment service area for increasing percentage of treated water. – Develop research project on sewerage system , WWT technology and water quality management	– Improve stakeholders coordination at improvement level – Improve law and regulations by decreasing the number of institutions involved and increasing cooperation among institutions. – Establish monitoring database and network. – Collaborative with financial institute for mega project
Threats	**ST Strategies**	**WT Strategies**
1. Economy and political crisis 2. Urbanization	– Install small-scaled on wastewater treatment in community. – Collaborate with government sectors, private sectors, and general public on water quality management. – Develop environmental friendly design for wastewater treatment project through community participate. – Improve sewerage collection system	– Strictly measures and enforcement of laws and regulation. – Pull and push methods of public participation and awareness. – Wastewater tariff will be collected together with water supply bill. – Set up land use zoning particularly in suburban area –

Source: SWOT analysis of Bangkok case, Thailand, 2011, unpublished.

Annex 2.3-7: Proposed strategies of urban water quality management in Metropolitan Ho Chi Minh City

INTERNAL FACTORS / EXTERNAL FACTORS	**Strengths**	**Weaknesses**
	1. Concern and ready cooperation of different management levels 2. Water resources are diverse and abundant	1. Lack of mechanism and policies for water quality management and less flexible 2. Water quality monitoring at upstream are not enough and weak
Opportunities	**SO Strategies**	**WO Strategies**
1. Capacity and collaboration on river basin management were more and more concerned 2. Enhanced community awareness	– Increase the cooperation on river basin management from central to local levels – Promulgate specific policies on water resources management which are both suitable for local sub-basin development and for the national goals – Complete and enhance inter-cooperation on water -quality monitoring in/cross the basins – Approach and apply the technological solutions for rational use and protection of water resources	– Issue new policies on water tariff which encourage water saving and protecting water resources – Increase the application of model science and technology on water quality monitoring – Promulgate the incentive policies and investments on scientific research on water quality management; invest in equipments, improve infrastructure for protecting and improving water quality – Minimize the impacts of climate changes on water resources
Threats	**ST Strategies**	**WT Strategies**
1. Climate changes 2. Poor performance of scientific engineering and infrastructures	– Disclosure and disseminate information on existing management of water quality – Share the water resources among water users along the basin – Apply the results of water-quality monitoring on identifying the sensitive and vulnerable areas to climate changes and increase the supervision and monitoring in those areas – Coordinate on management between levels to adapt to impacts of climate changes	– Encourage the community participation on water -quality monitoring and supervising – Add new policies on water quality management in association with scenarios of climate changes – Stimulate, encourage and support on using different water resources – Building capacity on advanced technology implementation on water quality management for managers

Source: SWOT analysis of Ho Chi Minh case, Vietnam, 2011, unpublished.

Annex 2.3-8: Proposed strategies of urban water quality management in Metropolitan Phnom Penh

INTERNAL FACTORS / EXTERNAL FACTORS	**Strengths** 1. Strong Government Commitment 2. Well Management Plan/Framework	**Weaknesses** 1. Lack of Monitoring/Enforcement 2. Non-Sufficient Budget of State Sector
Opportunities	**SO Strategies**	**WO Strategies**
1.Potential Supporting Fund of Donor 2.International Institution and NGO Participation	– Increase funding from donor by using strong government commitment – Use top management commitment to maximize international institution and NGO participation – Use well management plan/framework to increase funding from donor to manage river water quality – Enhance international institution and NGO participation by well management plan/framework	– Improve monitoring activities at local and ministry level – Improve law enforcement through stakeholder participation – Improve the amount of budget for monitoring and law enforcement – Improve budgeting by participating from stakeholders
Threats	**ST Strategies**	**WT Strategies**
1. Insufficient Capacity/Resource 2.Public Participation and Awareness	– Use top level commitment for building capacity of government staffs – Increase public participation and awareness in water quality monitoring using top commitment – Improve research capacity of government staffs in river water quality management and control – Increase public participation and awareness using well management plan/framework	– Develop capacity in water quality monitoring by strict law enforcement – Use strict law enforcement for public participation and improving awareness – Strict monitoring for violation of river water quality management policy – Use strict law enforcement to control solid and liquid waste from commercial and residential sector

Source: SWOT analysis of Phonm Penh case, Cambodia, 2011, unpublished.

RT

2.4 Application of SWAT to Predict Water Quality in the Chao Phraya River Basin

Application of the SWAT model for effective water resources management in the Chao Phraya River, Thailand

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2.4.1. Introduction

Water resources are considered is one of the world's most essential resources and is under continual threat due to pollution and scarcity (Beniston and Tol, 1998; Falkenmark and Rockstrom, 2004), especially as climate change is one such threatening factors for managing water resources due to its uncertainty and variability (Huntington, 2006). Climate change has caused significant changes in intensities and frequencies of rainfall, and thereby results in the variation of spatiotemporal distribution for water resources (Huntington, 2006). Furthermore, it is quite apparent that climate change influences variation in water quality due to potential effects from temperature and precipitation changes (Delpla et al., 2009). For instance, floods and droughts influenced by the climate change may lead to changes in water quality by enhancing erosion or dilution effects (Delpla et al., 2009).

It is challenging to mitigate the effect of the climate on water quantity and water quality, where policy makers should obtain scientific and predictive information. For effective water resources management, it is necessary to predict water quantity and water quality in response to potential climate change scenarios. The Soil and Water Assessment Tool (SWAT) is a watershed-scale and continuous-time model and mostly operates on a daily time step (Arnold et al., 1998). It was developed, and has been improved, by USDA-ARS, attempting to simulate a long term impact of agriculture-associated managements on water quantity and quality in a watershed. It is a physical-based, and semi-distributed, model and consists of weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management factors. In the SWAT model, a watershed is divided into several subbasins, which are further spilt into Hydrologic Response Units (HRUs) that are characterized by a single type of land use, management, and soil. The SWAT model is one of the more popular watershed models in United States, Europe, and has been employed even in Asia and Africa. The model has been applied to simulate a hydrologic cycle and water contamination by considering point/non-point sources. Models calibrated by watershed and water quality data has been used to forecast water quantity and quality in response to scenarios of land use and climate changes (Chaplot et al., 2003; Li et al., 2009; Schiling et al., 2009 Somura et al., 2009).

Chaplot et al (2003) applied the SWAT model to predict changes of suspended solid and nitrogen concentrations in response to changes of crops in Walnut watersheds at Iowa State. Schiling et al (2009) used the SWAT model to forecast how much runoff and evapotranspiration are changed by the expansion of corn areas in the Raccoon River watershed within Iowa State. Li (2009) simulated changes of soil water contents and evapotranspiration by land use and climate changes using SWAT model.

Somura et al (2009) used SWAT models to investigate impacts of climate change on water resources for the Hii River basin and downstream Lake Shinji.

Here, we have used the SWAT model to predict water quantity and quality in The Chao Phraya River, Thailand. The Chao Phraya River which is the largest river in Thailand has been contaminated by urbanization and agricultural activity (Simachaya et al., 2000). Therefore, effective management schemes should be addressed to improve the water quality in this river.

The objectives of this study are 1) to develop an assessment tool for modeling water quantity and quality in the Chao Phraya river basin, 2) to predict water quantity and quality in response to climate change scenarios, and 3) to evaluate the efficiency of structural BMPs in an attempt to improve water quality in the basin. The NIES (National Institute for Environmental Studies) MIROC3.2 hires model data were incorporated to predict future climate data in the basin, using downscaling and bias correction techniques.

2.4.2. Methods

1) Study area

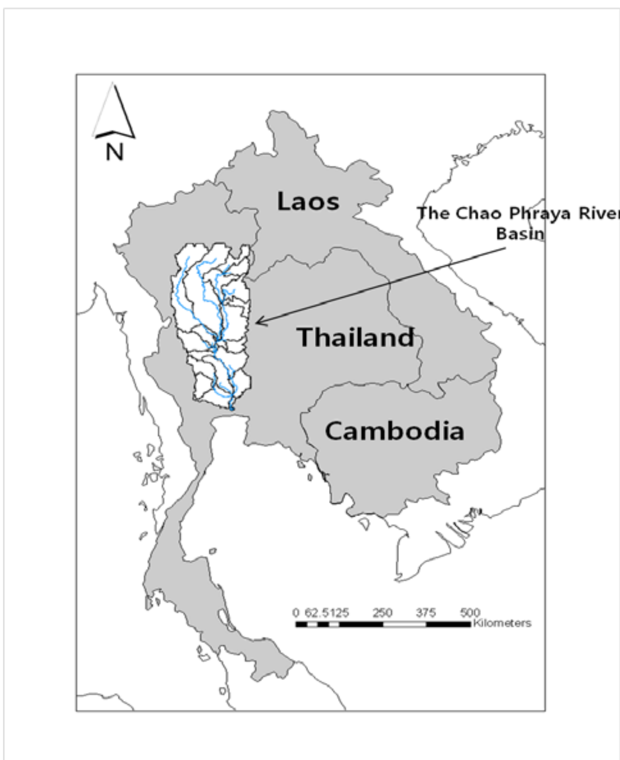


Figure 2.4-1: A map of the Chao Phraya River

The Chao Phraya River basin is approximately 160,000km^2 in area and flows into the gulf of Thailand, as shown in Figure 2.4-1. Flow rate and annual precipitation, and discharge in the watershed are 196 m^3/s and 1,179mm/year, respectively. Table 2.4-1 shows land use types and their percentages in the watershed, indicating that the watershed can be characterized by agricultural and urban areas. The water quality of the watershed has had issues from low dissolved oxygen and high nutrients, and fecal coliforms (Simachaya et al., 2000). The contamination sources and their contributions are highly variable, but nonpoint sources from urbanized and agricultural areas were mainly identified as the most significant sources in the watershed.

Table 2.4-1: Summary of the land use type area and percentage (UNESCO)

Feature	Value
Length (km)	374
Catchment area (km^2)	21,725
Forest	2.1%
Agriculture & Urban	92.7 %
Water	5.2%

2) Modeling approach

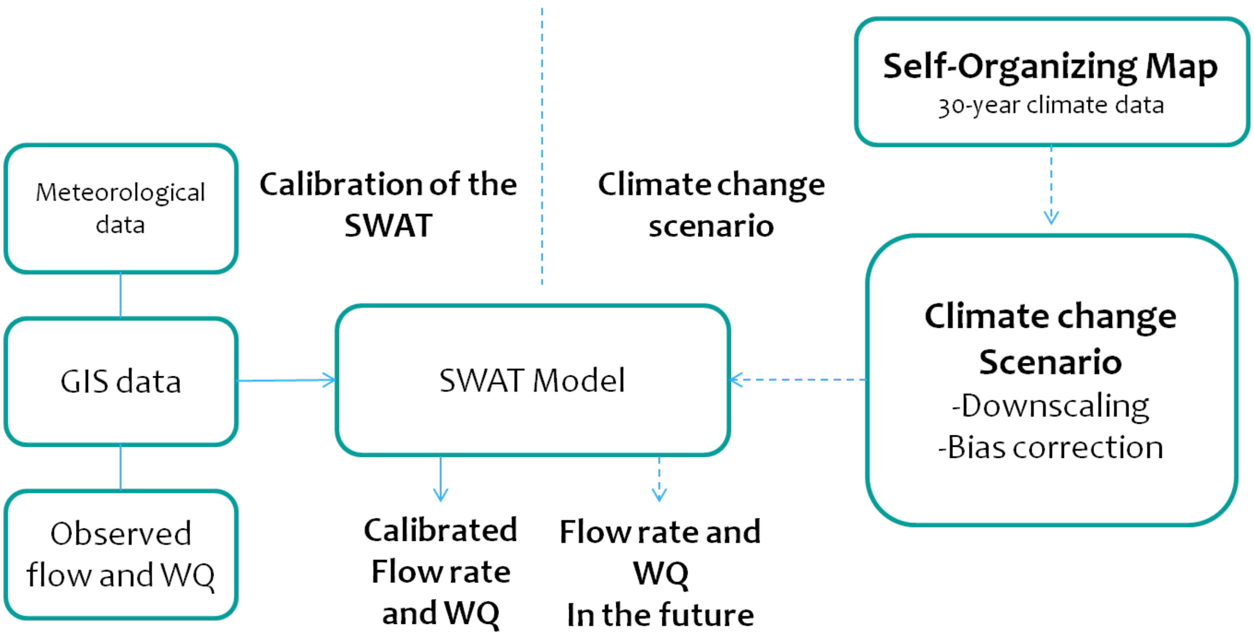


Figure 2.4-2: A flow chart for modeling water quality in the Chao Phraya River basin

Figure 2.4-2 illustrates a flow chart for the modeling strategy in the watershed which can be divided into two parts. One is a calibration process of the SWAT model and the other is the future water quality prediction under structural BMPs implementations. A self-organizing map, which is an example of neural networks, was applied to recover missing meteorological data that was used for bias correction. Three different best management practices were incorporated to the future scenarios analysis, attempting to compare their removal efficiencies.

3) Climate change scenarios

3.1) SOM application

The self-organizing map (SOM) has a rectangular grid with hexagonal or rectangular lattice which represents clusters having similar data. This clustering is based on an artificial neural network algorithm by computing Euclidean distances between sample vectors (from raw data) and virtual vectors (to set the location of sample vectors on SOM).

- The number of lattices has to be determined. When the number of input data is n, the number of lattice is calculated as $5\sqrt{n}$.

- A virtual vector is assigned to each lattice, and a sample vector is also assigned to each input data.

- Euclidean distance is calculated between each sample vector and virtual vector sequently.

- The sample vector is assigned to the lattice including virtual vector with the shortest Euclidean distance with the sample vector.

The Euclidean distance was the distance measurement method that provided the most accurate data representation on the map. The Davies–Bouldin Index (DBI) was calculated to identify the optimum number of clusters (Davies and Bouldin, 1979). SOM toolbox package for the method is available and freely downloadable from the web site of Helsinki University.

3.2) Downscaling and bias correction

In this study, National Institute for Environmental Studies (NIES) MICROC3.2 hires model was applied to obtain future climate data because of a good proximity to the watershed. The future climate data including precipitation and maximum and minimum temperatures were downscaled using LARS-WG (Semenov et al., 2002). 30-year data from 1980 to 2010 were used to perform bias correction. A grade stabilization structure was also included by using CH_EROD values.

4) Structural BMP scenarios

Three different structural BMP have been considered in the watershed and were compared in terms of pollutant loading. A filter strip was represented by adjusting FILTERW value (the width of the edge of field filter strip). A grassed waterway was explored by changing CH_EROD (the channel erodibility factor), channel cover factor (CH_COV), and Manning's n value for main channel. It is assume that a single type of BMP have been adapted for each subbain in the watershed.

2.4.3. Results and Discussion

1) Calibration of flow rate

Table 2.4-2 illustrates the sensitivity of the 27 hydrologic parameters within their ranges. The sum of squared error (SSE) between observed and predicted flow rates was set to be the objective function. The table shows that CN2 (Initial SCS runoff curve number for moisture condition II) was the most sensitive factor, influencing the hydrologic circulation of SWAT in the watershed, followed by SOL_K (Saturated hydraulic conductivity (mm/hr)), ESCO (Saturated hydraulic conductivity (mm/hr)), and SOL_Z (Depth from soil surface to bottom of layer (mm)). The 7 highly ranked parameters (S>0.1) were calibrated for predict flow rates at the monitoring station, except for watershed morphology parameters.

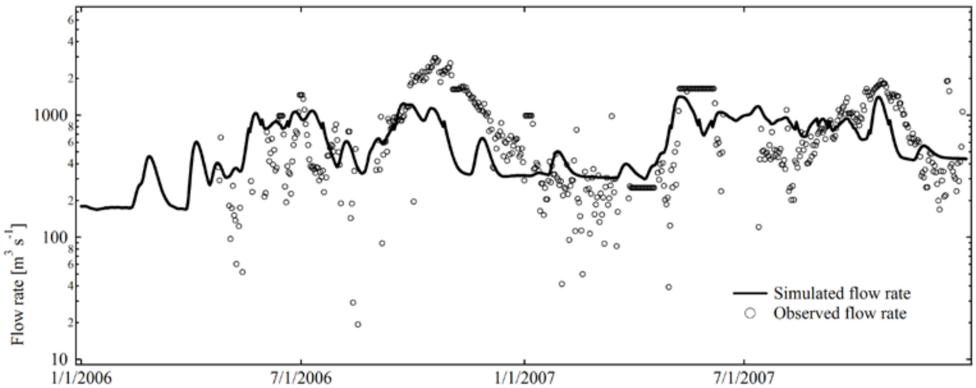


Figure 2.4-3: Comparison between simulated and observed flow rates

Figure 2.4-3 compares observed and predicted flow rates in the monitoring station, showing that the model well represented temporal variations of the observed flow rates. The prediction accuracy, however, was not satisfactory, showing a limitation to reproduce peak flow rates. This may attribute to the fact that the monitoring station is closely located in the Gulf of Thailand, and flow rates are affected by tidal effects. It may cause a significant dilution effect on water quality in the river.

2) Calibration of water quality

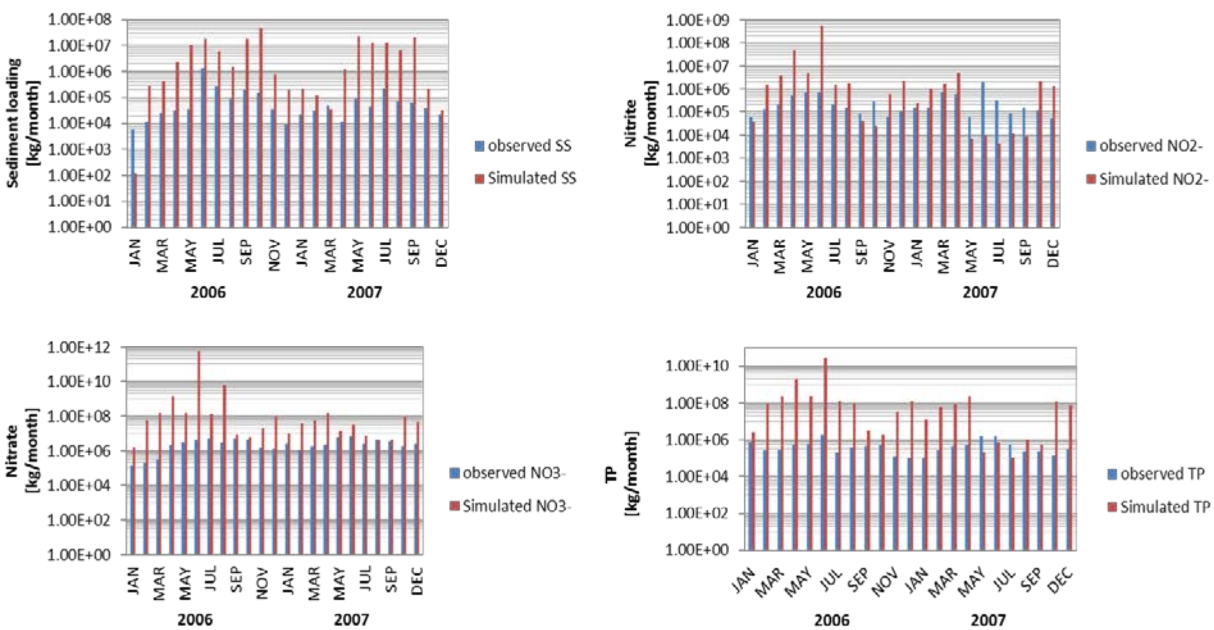


Figure 2.4-4: Comparison between simulated and observed pollutant loadings

Table 2.4-3: Hydrologic parameters for the sensitivity analysis with their ranges (from Min to Max), sensitivity rank, and sensitivity value.

Parameter	Min	Max	Rank	S	Value	Definition	process
CN2	35	98	1	3.50E+00		Initial SCS runoff curve number for moisture condition II	Runoff
SOL_K	-50	50	2	2.12E-01		Saturated hydraulic conductivity (mm/hr)	Snow
ESCO	0	1	3	1.56E-01		Soil evaporation compensation factor	Soil
SOL_Z	-50	50	4	1.55E-01		Depth from soil surface to bottom of layer (mm)	Groundwater
SOL_AWC	-50	50	5	6.78E-02		Available water capacity of the soil layer (mm H2O/mm soil)	Soil
CANMX	0	15	6	2.17E-02		Maximum canopy storage (mm H2O)	Geomorphology
SURLAG	0	10	7	1.78E-02		Surface runoff lag coefficient	Evaporation
SLOPE	-50	50	8	6.15E-03		[HRU_SLP] Average slope steepness (m/m)	Geomorphology
SOL_ALB	0	1	9	5.67E-03		Moist soil albedo	Evaporation
ALPHA_BF	0	1	10	5.13E-03		Baseflow alpha factor-Baseflow recession constant	Runoff
EPCO	-50	50	11	4.47E-03		Plant uptake compensation factor	Snow
CH_K2	0	150	12	4.46E-03		[CH_K(2)] Effective hydraulic conductivity in main channel alluv ium (mm/hr)	Channel
SLSUBBSN	-50	50	13	3.24E-03		Average slope length (m)	Snow
CH_N	-20	20	14	2.44E-03		Manning's "n" value	Runoff
SMFMX	0	10	28	0.00E+00		Melt factor for snow on June 21 (mm H2O/°C-day)	
SMFMN	0	10	28	0.00E+00		Melt factor for snow on December 21(mm H2O/°C-day)	
GWQMN	0	500 0	28	0.00E+00		Threshold depth of water in the shallow aquifer for return flow (mm H2O)	Soil
GW_REVAP	0.02	0.2	28	0.00E+00		Groundwater "revap" coefficient	Snow
REVAPMN	0	500	28	0.00E+00		Threshold depth of water in the shallow aquifer for percolation to the deep aquifer (mm H2O)	Evaporation
TLAPS	-50	50	28	0.00E+00		Temperature lapse rate (°C/km)	Snow
SFTMP	0	5	28	0.00E+00		Snowfall temperature (°C)	Channel
SMTMP	0	5	28	0.00E+00		Snow melt base temperature (°C)	Soil
TIMP	0.01	1	28	0.00E+00		Snow pack temperature lag factor	
GW_DELAY	0	100	28	0.00E+00		Groundwater delay time (days)	Groundwater
RCHRG_DP	0	1	28	0.00E+00		Deep aquifer percolation fraction	Groundwater
BLAI	-50	50	28	0.00E+00		Maximum potential leaf area index	Groundwater
BIOMIX	0	1	28	0.00E+00		Biological mixing efficiency	Soil

Figure 2.4-4 shows a comparison between observed and predicted pollutant loadings of sediment, nitrate, nitrite, and total phosphorus. The model overestimates four water quality loadings, showing a discrepancy during the observation period. The model showed a superior prediction on nitrite, but relatively poor performance in prediction of total phosphorus. It may be needed to obtain more information on agricultural activity in the watershed, such as manure and fertilizer application, and failing septic system distributions. As described above, because the monitoring station is close to the ocean, the observed water qualities may be diluted by sea water intrusion.

3) Recovery of missing data

Figure 2.4-5 compares observed and simulated precipitation by SOM with 3-year data, showing an open square area which indicates the recovered data. Here, the predictions by SOM slightly underestimated the observed precipitation, but well reproduced temporal variation of the observations. It demonstrates that SOM can be a tool to recover missing data, so GCM model results can be modified by bias correction. Figures 2.4-6 and 2.4-7 show comparisons of maximum and minimum temperatures, illustrating that SOM also can be used to recover missing data on temperature. The recovered data are further used to perform a bias correction on GCM results.

Maximum temperatures ranged from 25 ºC to 40 ºC, showing a yearly periodicity during the observation time. Simulated temperatures are less variable than observed temperatures, but well reproduce the temporal trend of the observation. Minimum temperatures vary between 15 ºC and 28 ºC, illustrating a clear yearly pattern. Predicted temperatures possess fewer variables than observed values, but demonstrate that they can be applied to recover missing temperature data.

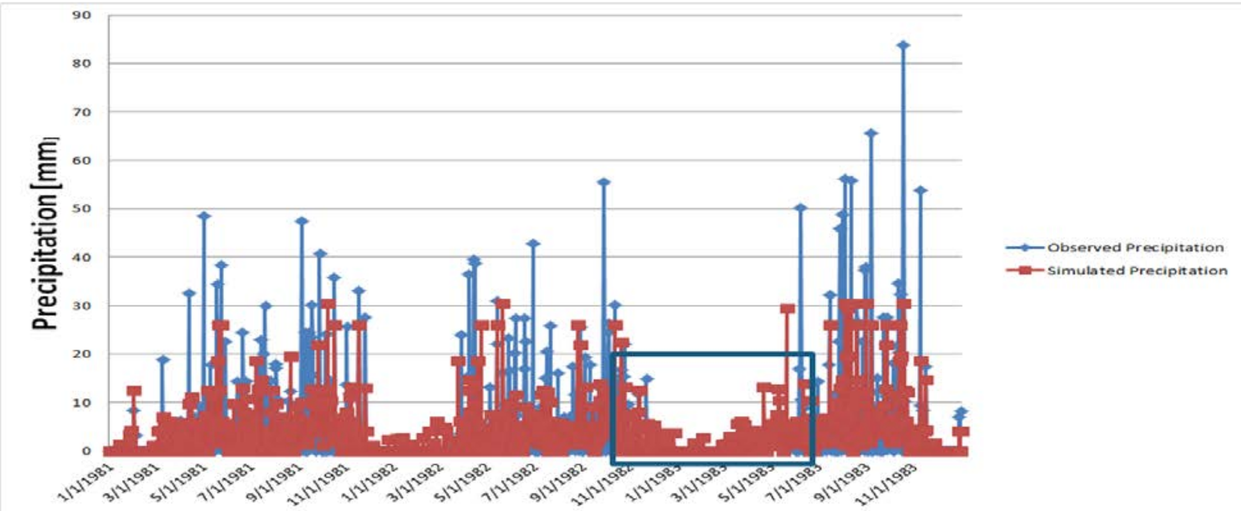


Figure 2.4-5: Comparison between simulated and observed precipitation

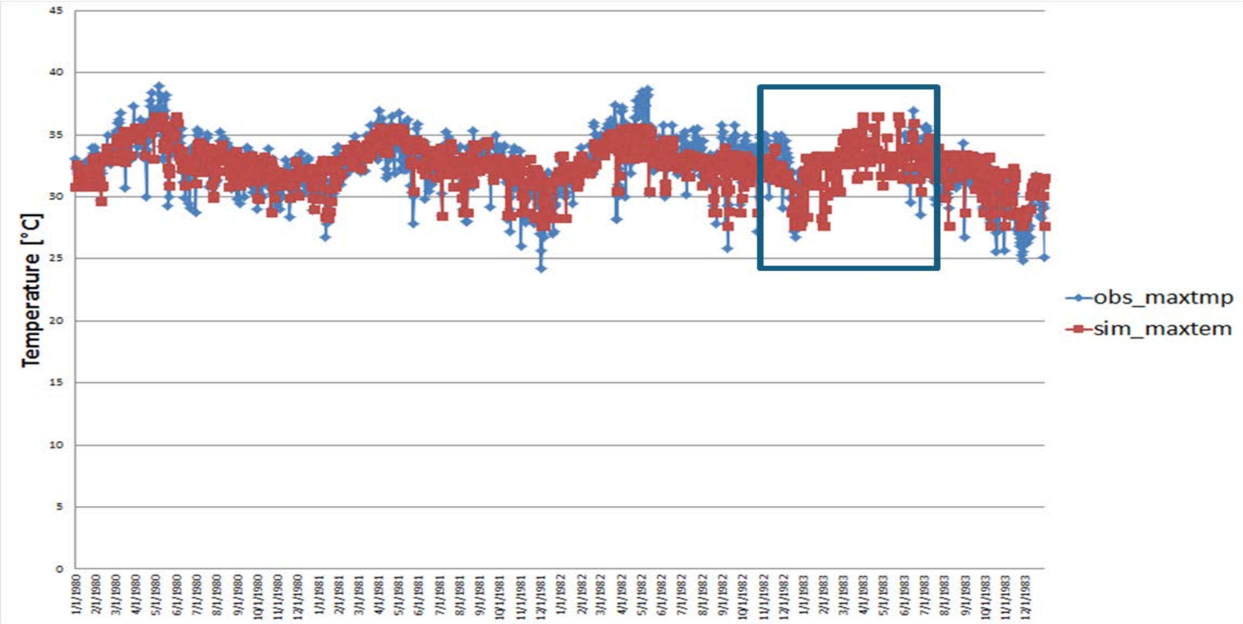


Figure 2.4-6: Comparison between simulated and observed maximum temperatures

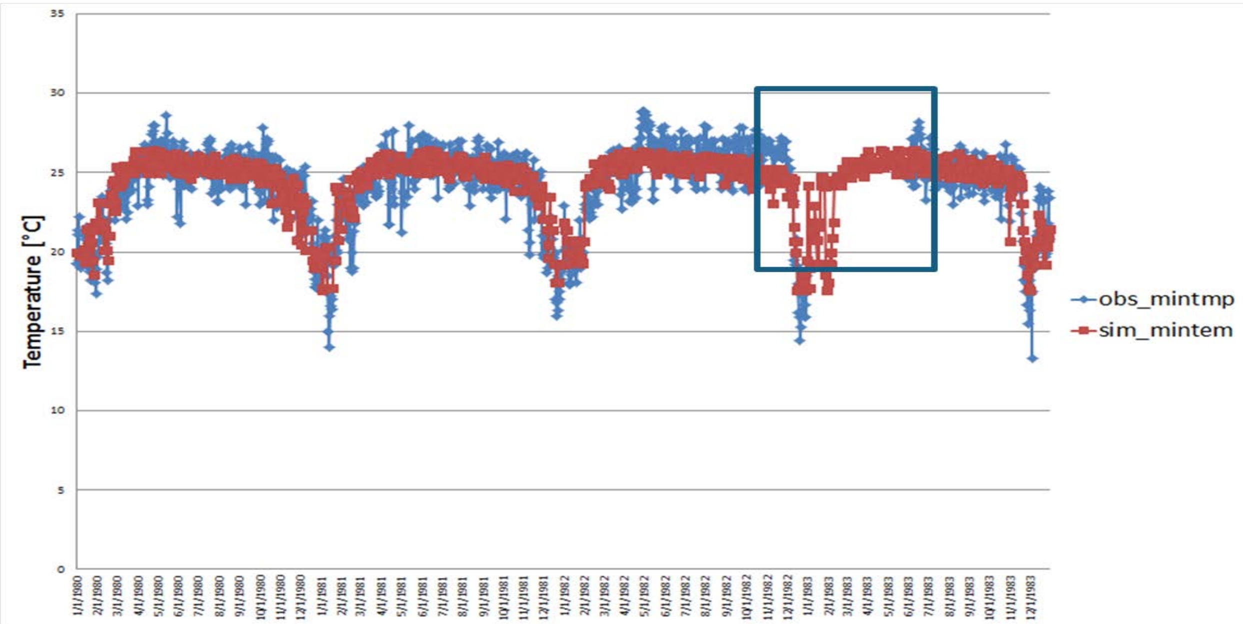


Figure 2.4-7: Comparison between simulated and observed minimum temperatures

4) Climate change scenarios

The A1B scenario was used to predict future climate, which can be applied to predict flow rates and water quality using the SWAT model. The A1B is a "middle" GHG emission scenario. The data is freely available as a download from the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Center (www.mad.zmaw.de/IPCC_DDC/html/SRES_AR4/index.html). Spatial resolution of the GCM data is not available for the SWAT modeling due to a scale difference. Two sequential steps were taken to make data available for SWAT modeling, bias correction and downscaling. For the first step of bias correction, correction factors were estimated by using 30-year meteorological data that had been recovered by SOM. LARS-WG was used to generate daily meteorological data for the next 100-years.

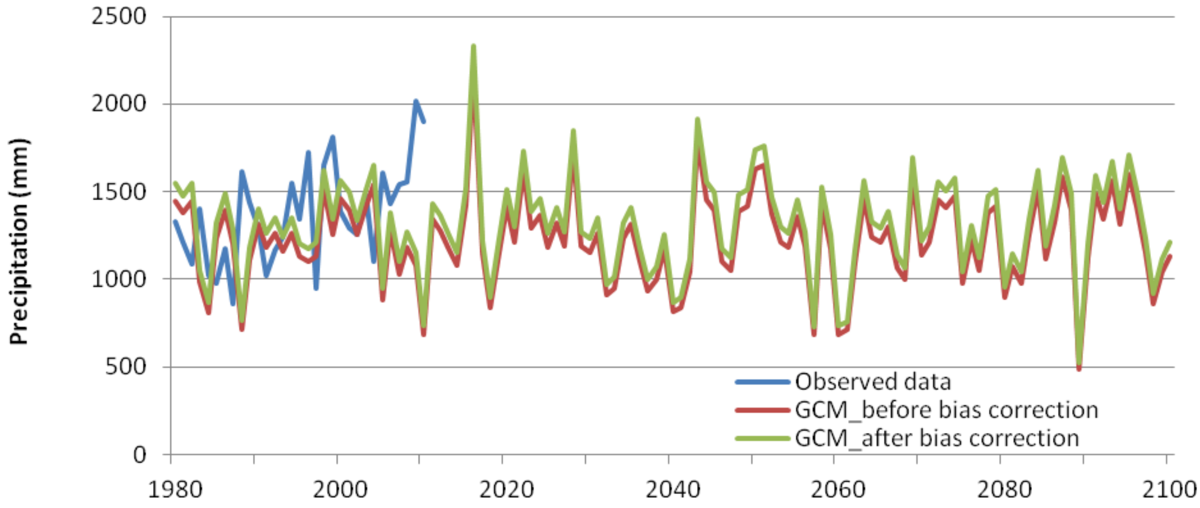


Figure 2.4-8: Predicted precipitation from the GCM model

Figure 2.4-8 shows the GCM-generated prediction, comparing with observed data during 1980 to 2009. The GCM model results were categorized into two periods, the 2040s (2021-2060) and the 2080s (2061-2100), to quantify how much climate had changed. The GCM model well reproduces the temporal variation of precipitation from 1980 to around 2003, but shows relatively poor prediction after that period. In 2017, the precipitation from GCM model shows a peak value, and is considerably fluctuated. The averaged precipitation in 2080s had increased by 0.20 mm compared to 2040s.

Figure 2.4-9 shows the GCM model on maximum temperature comparing 30-year observation data. Variability of the observation was not significant, so it allowed the GCM model to easily follow trends. The GCM model results had been substantially improved by applying a bias correction factor, showing an increasing trend. The averaged precipitation in 2080s is 35.04 ºC which is greater than that of 2040s (34.16 ºC) by 0.87 ºC.

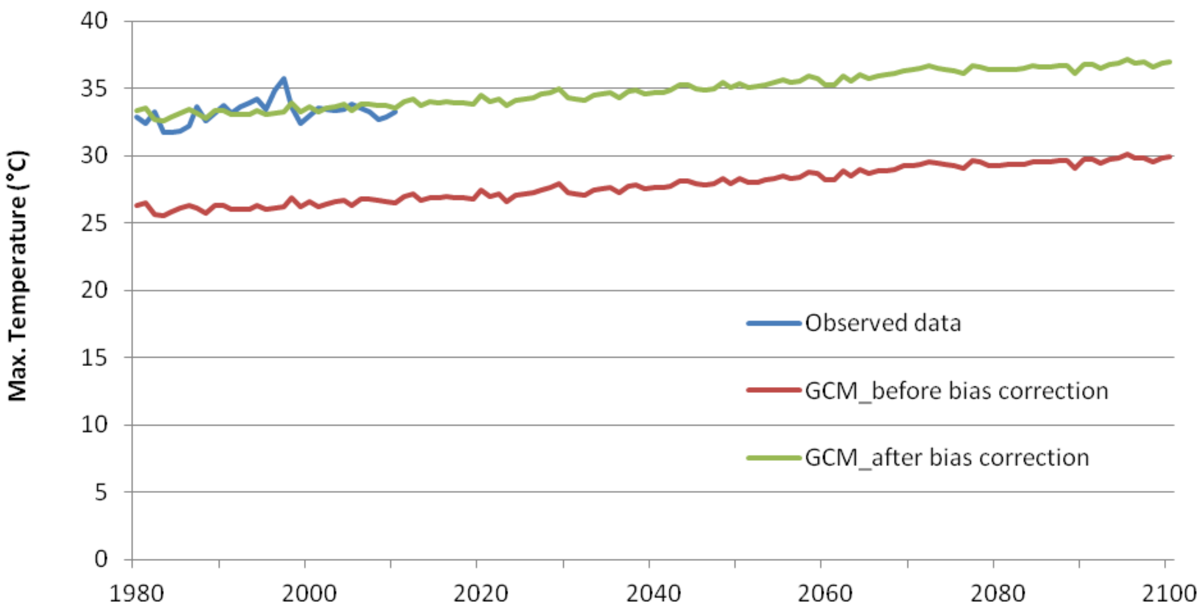


Figure 9: Predicted maximum temperature from the GCM model

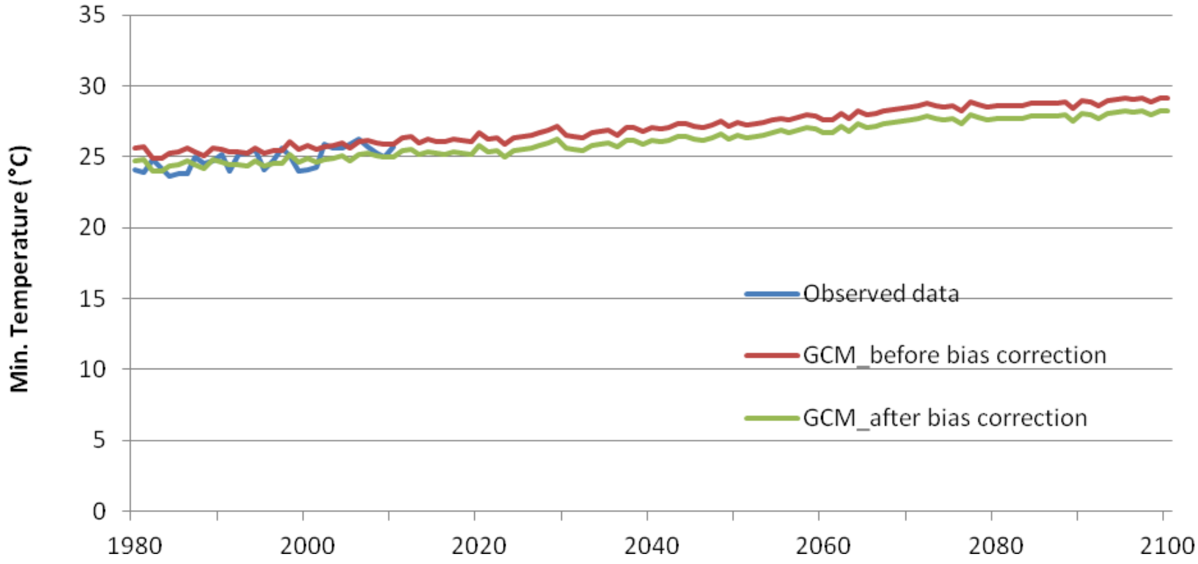
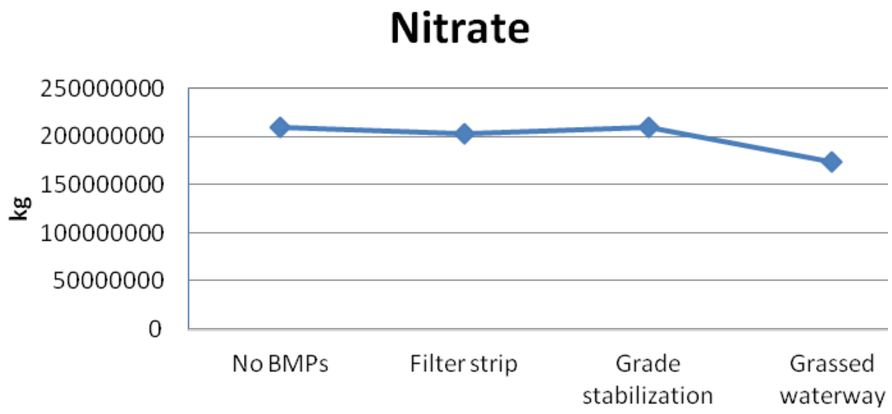


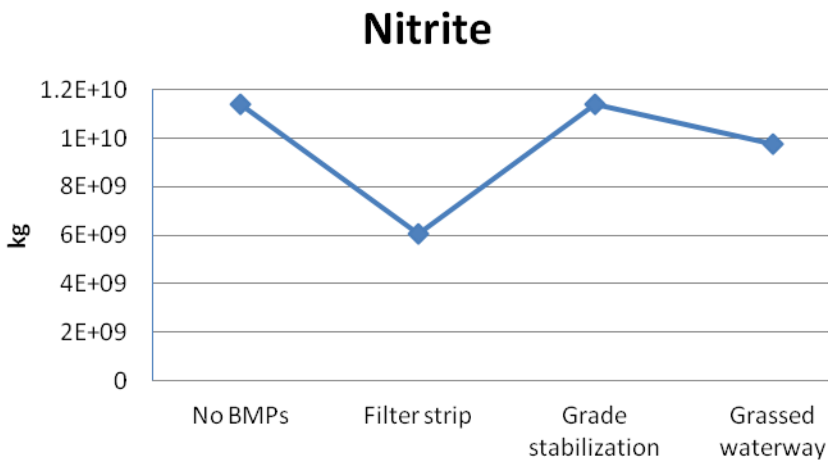
Figure 2.4-10: Predicted minimum temperature from the GCM model

Figure 2.4-10 shows the GCM model on minimum temperature, comparing 30-year observation data. The temporal variation of minimum temporal is very insignificant, as much as the maximum temperature. It is quite obvious that temperature has been increased during the prediction period. The averaged minimum temperature in 2060s is 26.47 ºC which is greater than that of 2040s (25.60 ºC) by 0.87 ºC.

5) Structural BMP implementation

Figure 2.4-11 illustrates nitrate, nitrite and total phosphorus loading in response to different types of structural BMPs. Overall filter stripping was the most superior strategy in terms of nutrient loading reduction within the watershed. For nitrite and total phosphorus, filter stripping was the most efficient BMPs to reduce loadings, showing significant reduction rates. Grassed waterways were superior BMP to reduce loading of nitrate.





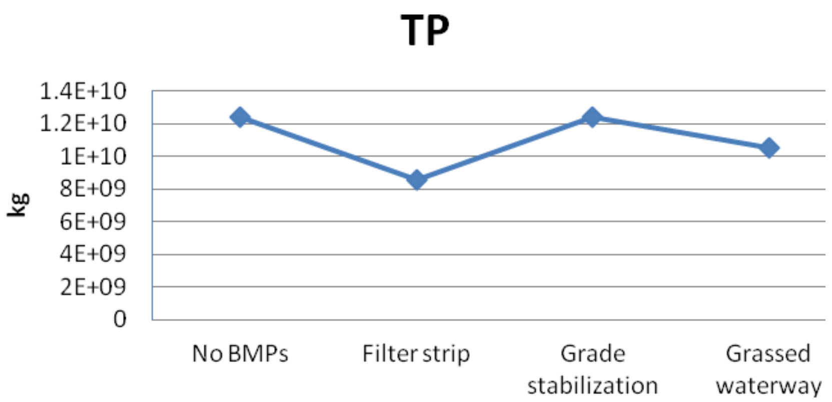


Figure 2.4-11: Pollutants loadings in respond to different type of BMPs

2.4.4. Conclusion

This modeling study needs to be enhanced by collecting more watershed-associated data and using high-resolution Hydrology Response Unit (HRUs) in the SWAT model. As well, more suitable monitoring stations for water quality and quantity are needed, where the tidal effect on monitoring stations should be insignificant. These effects will promise more accurate and liable modeling results and address predictive information for effective water resources management schemes. In addition, there are substantial uncertainties to accurately predict precipitation and temperature in the future because a feedback process between climate and land surface was not considered. It will be a better approach if a global-scale climate change model is replaced with a regional model, considering land use change and its impact on water quality. This would allow for more realistic future climate data, as well water quantity and quality prediction.

For the BMP implementations, it may be needed to consider costs if installing and managing structural BMPs for a better assessment. Furthermore it is necessary to optimize types, and locations, of BMPs in the watershed when attempting to minimize costs and maximize BMP performance. This work provides a preliminary study, showing brief modeling results by coupling the SWAT model with GCM model in a similar fashion to those in neural networks. This research demonstrates that it could serves as a framework for further dynamic modeling work.

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2.5 Development of Water Quality Indexes to Identify Pollutants in Vietnam's Surface Water

Development of Water Quality Indices to Identify Pollutants in Vietnam's Surface Water

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Abstract

This study presents the first water quality indices developed to evaluate surface water in Vietnam. The basic water quality index (WQI_B) can be effectively used to evaluate the spatial and temporal variations of surface water quality as well as to identify water pollutants. The overall water quality index (WQI_O) can provide additional information, particularly on toxic substances contributing to water pollution. The water quality indices here developed were applied to the national surface water quality monitoring data taken from 1999 to 2007. Water pollutants were classified into three subcategories: organic and nutrients, particulates and bacteria. Surface water quality in northern and central Vietnam was poor, containing organic matter, nutrients and bacteria, while water in the southern part was mainly polluted by bacteria. Trend analysis results reveal deterioration in water quality in those provinces under pressure from rapid population growth, urbanization and industrialisation. Vietnam has established an official policy of comprehensive nationwide water quality monitoring by 2020. The implementation of water quality indices can provide guiding data for sustainable water resource management in Vietnam.

Keywords: surface water, water quality indices, evaluation, principal component analysis, rating curve, Vietnam.

2.5.1 Introduction

Assessment of water quality is very important to human health and a safe environment. A water quality index (WQI) is a means of summarizing large amounts of water quality data into simple terms (e.g., good, fair, poor) for reporting to policy makers and the public in a comprehensive, consistent manner (CCME, 2001). A water quality index makes information more easily and rapidly interpretable than a list of numerical values. The concept of the WQI was first introduced more than 150 years ago in Germany, where the presence or absence of certain organisms in water was used as an indicator of the fitness of a water source (Ott, 1978). It is believed that Horton's index (1965) started the trend toward using numerical scales to assess water quality. Since that time, numerous water quality indices have been developed and applied throughout the world (Couillard and Lefebvre, 1985).

In Vietnam, the national surface water monitoring network was established in 1996 by the Vietnamese Environmental Protection Agency (VEPA). Water quality monitoring data are collected and used for reporting the national environmental status every year. However, water quality is evaluated only by comparing individual parameters with the Vietnamese surface water standard. An overall water quality evaluation, as well as water quality comparisons of different monitoring sites both within a region and among different regions, had not yet been conducted. This was because no evaluation tool had been implemented. The objectives of this study are (1) to develop water quality indices for evaluating surface water quality and identifying water pollutants in Vietnam. These indices can then be used as a tool to communicate about surface water quality among scientists, decision-makers and the general public. Also, (2) to apply the developed WQIs to evaluate, for the first time, water quality of important water bodies in Vietnam, using national surface water monitoring data from 1999 to 2007.

2.5.2 Materials and methods

1) Study area

Figure 2.5-1 presents the existing national surface water monitoring network of Vietnam, covering almost 100 stations in 17 provinces. The main purpose of this monitoring network is water pollution assessment. The monitoring sites include lakes, rivers and streams, which are mainly in urban locations, near residential areas or close to factories or industrial zones. Twenty-seven water quality parameters have been monitored: pH, dissolved oxygen (DO), water temperature (Tw), turbidity, conductivity, suspended solids (SS), total dissolved solids (TDS), chloride (Cl^-), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total coliforms (T. coli), fecal coliforms, ammonium-nitrogen (NH_4^+-N), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), orthophosphate-phosphorus (PO_4^{3-}-P), total phosphorus, oil and grease, heavy metals: Iron (Fe), Lead (Pb), Cadmium (Cd), Mercury (Hg), Zinc (Zn), Copper (Cu), Nickel (Ni), Chromium (Cr) and pesticides.

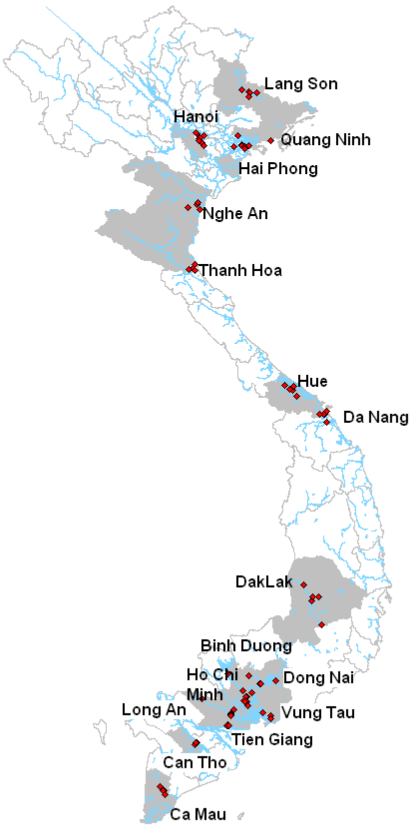

Figure 2.5-1: Existing national surface water quality monitoring network

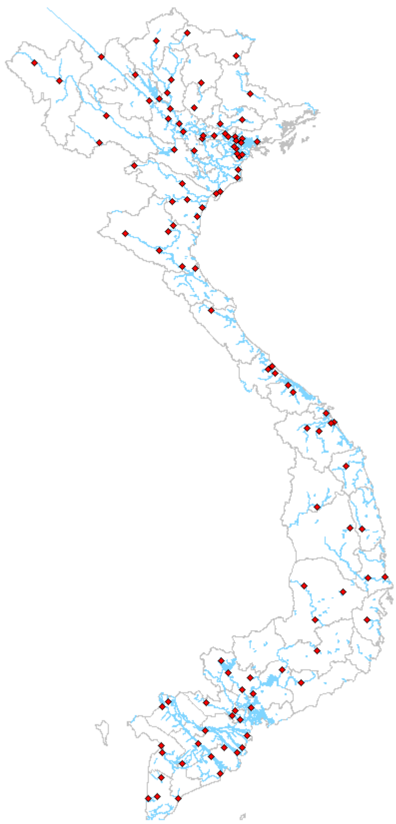

Figure 2.5-2: Proposed national surface water quality monitoring network in the year 2020

Source: Vietnam Environmental Protection Agency

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2) Development of water quality indices

Water quality indices were developed in three steps. Step 1 was parameters selection. Water quality parameters were set according to the following criteria. Firstly, the selected parameters should represent the overall water quality status and reflect each impairment category for freshwater systems (Dunnette, 1979), including oxygen status, eutrophication, health aspects, physical characteristics and dissolved substances. Secondly, they should be included in Vietnam's surface water standards, to allow the building of rating curves. Thirdly, for utility of a WQI within Vietnam, chosen parameters should be among the national monitoring program's existing surface water monitoring parameters. Finally, parameters which are most often monitored and have known significant effects on water quality should be selected. In Step 2, the rating curves method was applied to transform the concentrations of water quality variables into quality scores. In Step 3, a hybrid aggregation function of additive and multiplicative forms suggested by Liou et al., 2004, was used to aggregate sub-indices to produce a final index score. Principal component analysis (PCA) was applied to divide the selected parameters into groups. In this method, the original variables were transformed into new uncorrelated variables, called the principal components (PC). The PC can be expressed as:

$$z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \ldots + a_{im}x_{mj} \quad (1)$$

where *z* is the component score, *a* is the component loading, *x* is the measured value of variable, *i* is the component number, *j* is the sample number and *m* is the total number of variables.

The number of principal components to remain and their component loadings are characterized by eigenvalues, percent of total variance and cumulative percentage. All of these statistical tests are provided in SPSS 15.0 for Windows.

3) Statistical analysis

Surface water quality trends for each province, as well as for the whole country, over the period studied (1999 to 2007) were analysed by applying a basic linear regression-based model, with time of year as an independent variable and water quality index as a time-dependent variable, and tested by one-way ANOVA. To find the forces driving degradation trends in water quality for the provinces studied, Pearson's correlations between water quality index and population growth, urbanization and industrialization were determined. Urbanization was reflected by the ratio between urban population to total population, and industrialization was reflected by the percentage of industrial sector gross product to the total gross combined product of industry, agriculture, forestry, and aquaculture. All the statistical processes were performed using SPSS 15.0 software for Windows.

2.5.3. Results and discussion

1) Development of water quality indices

Water quality parameters selection

Water quality monitoring data show that among 27 parameters, 8 parameters: SS, turbidity, DO, COD, BOD_5, PO_4^{3-}-P, NH_4^+-N and T. coli, are the most frequently monitored and important parameters for water quality evaluation, because their measured concentrations often exceed the Vietnamese surface water standards. The toxic parameters such as cyanide, heavy metals, phenols and pesticides are also of concern, even though they have been less monitored. The monitoring parameters can therefore be divided into two groups. The basic group, comprising the eight mentioned parameters, can be used for the purpose of spatial and temporal water quality comparison as well as identification of water pollutants. The additional, less-monitored group, including water Tw, pH and toxic substances (phenols, pesticides, cyanide and heavy metals) that can provide needed information, especially on toxic pollutants.

Transforming the concentrations of selected water quality parameters into a common scale

Rating curves for all the water quality variables included in the list of Vietnamese surface water quality standards were developed. The range of water quality parameters and their 5 key-points defined for rating curves were presented in Table 2.5-1. Based on these rating curves, parameter concentrations received final scores between 1 (the worse case) and 100 (the best case). The curves are in the piecewise linear membership functions form (Figure 2.5-3). The bases of such functions were Vietnam's national technical regulations on surface water quality (QCVN 08: 2008/BTNMT) and industrial waste water discharge standards (TCVN 5945: 2005). The rating curves for turbidity and saturated DO were developed by adopting the classification proposed by Pesce and Wunderlin (2000) and Prati et al. (1971). Temperature dependent saturated DO concentration was calculated by the following empirical formula (Elmore and Hayes, 1960):

$$C_S = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3 \quad (2)$$

where:

Cs: saturated DO concentration (mg/l)

T: water temperature (^{o}C)

Five levels of water quality are determined according to the QCVN 08: 2008/BTNMT and TCVN 5945: 2005 as following (Table 2.5-1):

- Level 1: surface water that can be used for the purpose of domestic water supply
- Level 2: surface water using for a source of domestic water supply with appropriate treatments or for protection of aquatic life
- Level 3: surface water can be used for irrigation purpose
- Level 4: surface water can be used for other purposes that need lower water quality such as navigation
- Level 5: waste water that can be discharged into the permitted water bodies for further treatment only.

Table 2.5-1: The range of water quality parameters and their key-points defined for rating curves

Parameter	Unit	Score value				
		100	75	50	25	1
		Level 1	Level 2	Level 3	Level 4	Level 5
pH	-	6-8.5	6-8.5	5.5-9	5.5-9	5.5-9.0
Temperature	^0C	-	-	-	-	40
DO saturated	%	88-112	75-88 112-125	50-75 125-150	20-50 150-200	<20 and >200
Turbidity	NTU	5	20	30	70	100
SS	mg/l	20	30	50	100	100
COD	mg/l	10	15	30	50	80
BOD	mg/l	4	6	15	25	50
Ammonium (as N)	mg/l	0.1	0.2	0.5	1	10
Nitrite (as N)	mg/l	0.01	0.02	0.04	0.05	-
Nitrate (as N)	mg/l	2	5	10	15	-
Orthophosphate (as P)	mg/l	0.1	0.2	0.3	0.5	-
Chlorine	mg/l	250	400	600	-	600
Fluorine	mg/l	1	1.5	1.5	2	10
Cyanide	mg/l	0.005	0.01	0.02	0.02	0.1
Arsenic	mg/l	0.01	0.02	0.05	0.1	0.1
Cadmium	mg/l	0.005	0.005	0.01	0.01	0.01
Lead	mg/l	0.02	0.02	0.05	0.05	0.5
Chrome (3)	mg/l	0.05	0.1	0.5	1	-
Chrome (6)	mg/l	0.01	0.02	0.04	0.05	-
Copper	mg/l	0.1	0.2	0.5	1	2
Zinc	mg/l	0.5	1	1.5	2	3
Ni	mg/l	0.1	0.1	0.1	0.1	0.5
Total iron	mg/l	0.5	1	1.5	2	5
Mercury	mg/l	0.001	0.001	0.001	0.002	0.01
Manganese	mg/l	0.1	-	0.8	-	1
oils and grease	mg/l	0.01	0.02	0.1	0.3	-

Phenol	mg/l	0.005	0.005	0.01	0.02	0.5
E. coli or thermotolerant coliform bacteria	most probable number /100ml	20	50	100	200	-
Total coliform	most probable number /100ml	2500	5000	7500	10000	-

Aggregation functions

Three components of the basic parameter group were extracted by principal component analysis (Table 2.5-2). The first component accounted for 46.56% of total variance, indicating strong positive loadings on BOD_5, COD, NH_4^+-N and PO_4^{3-}-P, and moderate negative loading on DO, according to the factor classification by Liu et al. (2003). High levels of organic matter and nutrients consume large amounts of dissolved oxygen. This component can be denoted as organic and nutrients pollution. The second component, assigned as particulates pollution, correlated strongly with suspended solids and turbidity, and explained 24.02% of total variance. The third component, accounting for 12.54% of total variance, was contributed by T. coli only. This component is responsible for bacteria pollution.

The aggregation function for the basic water quality indicator (WQI_B) is therefore proposed as:

$$WQI_B = \left[\frac{1}{5}\sum_{i=1}^{5} q_i \times \frac{1}{2}\sum_{j=1}^{2} q_j \times q_k \right]^{1/3} \quad (3)$$

where:

WQI_B: the basic water quality index

q_i: sub-index value of the organic and nutrients group containing DO, BOD_5, COD, NH^+_4-N and PO_4^{3-}-P

q_j: sub-index value of the particulates group containing SS and turbidity

q_k: sub-index value of the bacteria group containing only T. coli

Both the basic parameter and additional parameter groups were used to form the overall water quality index (WQI_O). The sub-indices for additional water quality parameters were first calculated. Each sub-index then was compared with the WQI_B, and taken into account only if it was lower. The Tw and pH coefficients were calculated directly from their respective sub-indices. The toxic coefficient was calculated by averaging all scores of toxic substances (Table 2.5-3 and 2.5-4). Since the WQI_O values were scaled between 1 and 100, the Tw, pH and toxic coefficients were scaled between 0.01 and 1. The WQI_O aggregation function is therefore proposed as:

$$WQI_O = \left(\prod_{1}^{n} C_i \right)^{1/n} \left[\frac{1}{5}\sum_{i=1}^{5} q_i \times \frac{1}{2}\sum_{j=1}^{2} q_j \times q_k \right]^{1/3} \quad (4)$$

where:

C_i : coefficients addressing the sub-indices of Tw, pH and toxic substances n: number of coefficients

Water quality then can be classified based on the WQI_B or WQI_O score as follows: 91 to 100-Excellent water quality, 76 to 90-Good water quality, 51 to 75-Fair, 26 to 50-Marginal and 1 to 25-Poor water quality.

Table 2.5-2: The component matrix, eigenvalues and accumulative percentages for the extracted principal components

	PC1	PC2	PC3
Loading of variables			
DO	**-0.713**	0.079	-0.015
Turb	0.067	**0.979**	0.017
SS	0.104	**0.975**	-0.024
BOD_5	**0.929**	-0.040	-0.061
COD	**0.912**	-0.002	-0.059
T. coli	0.073	0.009	**0.994**
NH_4^+-N	**0.798**	-0.066	0.074
PO_4^{3-}-P	**0.929**	-0.022	-0.033
Eigenvalues	3.724	1.922	1.003
% of total variance	46.56	24.02	12.54
Cumulative %	46.56	70.58	83.12

Table 2.5-3: Example of WQI_B and WQI_O calculation for the Red River sample

Parameter	Concentration	Sub-index score	$\frac{1}{5}\sum_{j=1}^{2} qi$	$\frac{1}{2}\sum_{j=1}^{2} q_j$	q_k	I_B	C_i	I_O
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			87.27	90.05	100	92.28	61.01	56.30
DO (mg/l)	5.03							
DO saturated (mg/l)	7.65							
% of DO saturated	65.74	65.74						
BOD_5 (mg/l)	7.58	70.60						
COD (mg/l)	9.88	100						
PO_4^{3-}-P (mg/l)	0.095	100						
NH_4^+-N (mg/l)	0.047	100						
SS (mg/l)	17	100						
Turbidity (NTU)	16.9	80.11						
T. coli (#/100ml)	550	100						
pH	7.9	100						
Tw (^{0}C)	28.5	100						
Cd (mg/l)	0.008	70.00						
Pb (mg/l)	0.059	49.02						
Fe (mg/l)	1.22	64.00						

$$Column\ (4): \frac{1}{5}\sum_{j=1}^{2} qi = \frac{65.74+70+100+100+100}{5} = 87.27$$

$$Column\ (5): \frac{1}{2}\sum_{j=1}^{2} q_j = \frac{80.11+100}{2} = 90.05$$

$$Column\ (6): q_k = 100$$

$$Column\ (7): WQI_B = \left[\frac{1}{5}\sum_{i=1}^{5} q_i \times \frac{1}{2}\sum_{j=1}^{2} q_j \times q_k\right]^{1/3} = 92.28$$

$$Column\ (8): \left(\prod_{1}^{n} C_i\right)^{1/n} = \left[\frac{1}{100} \times \frac{(70+49.2+64)}{3}\right]^{1} = 0.61$$

$$Column\ (9): WQI_O = \left(\prod_{1}^{n} C_i\right)^{1/n} \times WQI_B = 0.61 \times 92.28 = 56.30$$

Table 2.5-4: Example of WQI calculation results report

Sample description		Index		Critical parameter			Water quality
Location	Time	Basic	Overall	Name	Concentration	Sub-index	
Red river	23/4/2002	92.28	56.30	Pb (mg/l)	0.059	49.02	Fair

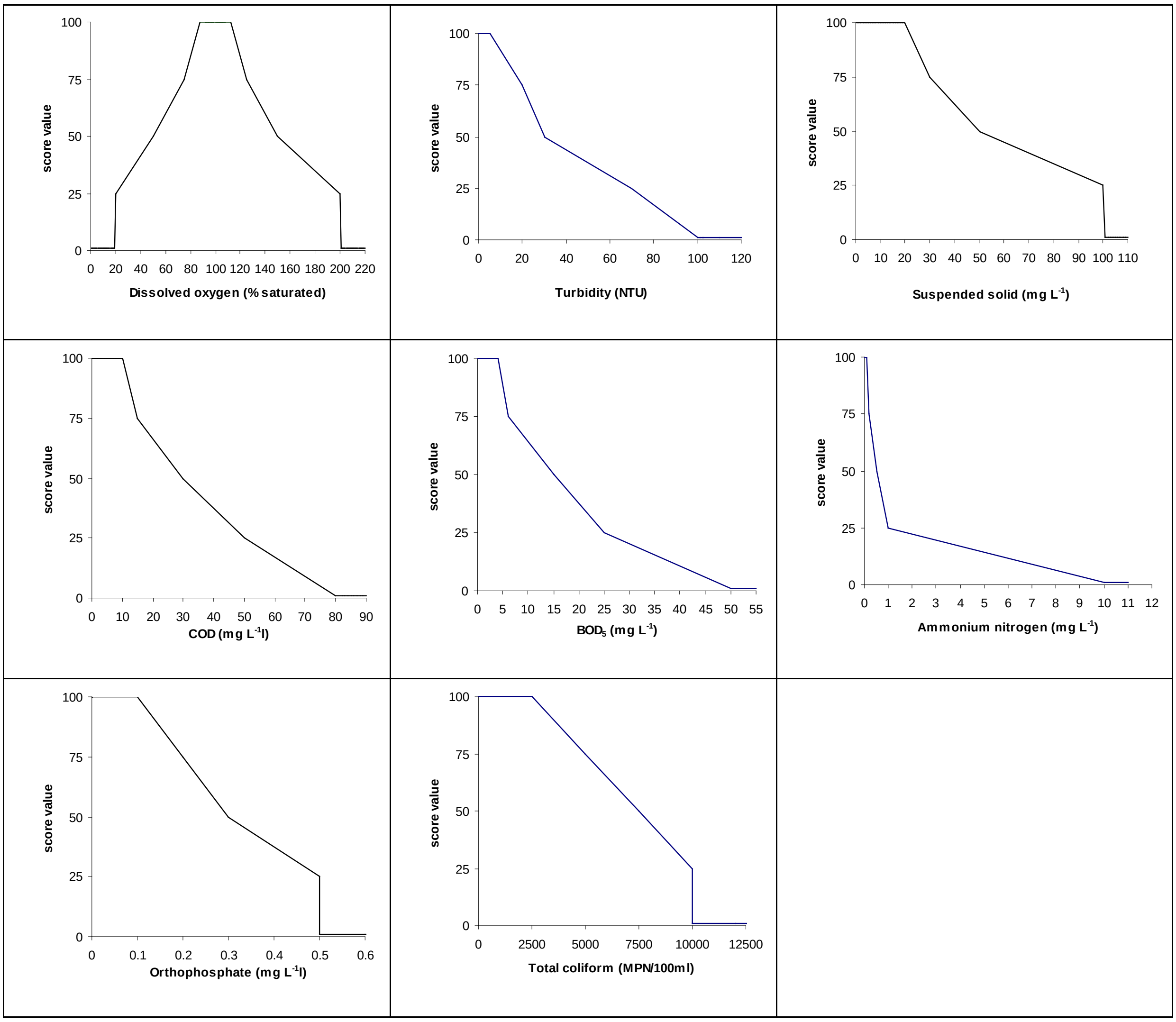

Figure 2.5-3: The assigned rating curves for the studied water quality variables

2) Application of the water quality indices to national water monitoring data

Evaluation of water quality

The WQI_B was calculated for all 3425 samples taken from 98 sampling stations from 1999 to 2007. In northern Vietnam, there are 24 monitoring sites in 4 provinces (Lang Son, Quang Ninh, Hai Phong and Ha Noi). Calculated WQI_B values show only one sampling site (4.17% of total sites) classified as good, while eight sites (33.33%) are with poor water quality. Water quality in particular represents the sampling sites' geographic locations. Severe pollution in the Hanoi and Lang Son drainage systems reveals the impacts of municipal and industrial waste water on water quality. The West Lake site located in inner Hanoi was an exception because of the self purification from this very large water body (more than 500 hectare), ranked as fair water quality. Fair to good water quality was detected in the Ky Cung River's sites in the suburb of Lang Son. Furthermore, WQI_B can help identify water pollutants. Figure 2.5-4 presents the absolute and relative scores of three subcategories (bacteria, particulates and organic and nutrients) in the WQI_B calculated for northern Vietnam. In this figure the relative scores (presented as percentages) can be interpreted such that, the lower the score for a group, the more heavily the water is polluted by that group. It is found that drainage systems in inner Hanoi and Lang Son were severely polluted by organic matter and nutrients as well as bacteria (scoring 1.1-7.09 and 1.0-17.56, respectively). Lakes located in inner Hanoi, Hai Phong and Lang Son were classified as poor to moderate in quality on organic and nutrients (scoring 19.37-42.60) and marginal to fair on bacteria (scoring 36.18-72.46) and particulates (47.37-67.83). The main problem with river water quality (except the Ky Cung River) however, were particulates, ranked as very poor to moderate in quality (scoring 6.45-42.29). Organic matter and nutrients (scoring 52.29-71.30) and bacteria (50.90-100) were not of big concern. The Ky Cung River (Lang Son Province), classified as the most clean among the monitored water bodies in northern Vietnam, had fair to relatively good conditions for all three subcategories (scoring 60.58-90.22).

In the central part of Vietnam, five provinces/cities (Thanh Hoa, Vinh, Hue, Da Nang and Daklak) with a total of 24 sites were monitored for surface water quality. The WQI_B shows water quality mainly ranked as marginal, as at 66.67%, for the sampling sites. Water quality in Da Nang and Daklak was worse than in other provinces. A breakdown of three water quality subcategories in central Vietnam is presented in Figure 2.5-5. The main pollutant factor was bacteria for these two provinces' water bodies, scoring 21.11-37.81 in Da Nang and 7.43-40.70 in Daklak. Among the central provinces, Hue had the highest surface water quality (scoring 68.24±22.33). Huong River water quality (scoring 69.15-76.34) was much better than that of other water bodies in Hue city. Lakes and rivers located in inner Hue were polluted either by bacteria (scoring 26.0 in the An Cuu River) or by organic matter and nutrients (scoring 34.8 in Tinh Tam Lake). Water quality in Thanh Hoa and Vinh was classified from marginal to fair. Better scores were obtained from large rivers outside cities, such as the Ma River in Thanh Hoa (scoring 63.45), the Dao Cua Tien River (58.11) and the Lam (70.38) in Vinh. Other water bodies in the inner cities, however, were in relatively poor condition for bacteria (Cua Nam Lake scoring 17.73), and organic matter and nutrients (36.21 for Thanh Lake).

Fifty sampling sites in eight provinces (Ho Chi Minh, Vung Tau, Binh Duong, Can Tho, Dong Nai, Long An, Tien Giang and Ca Mau) located in the southern economic development zone of Vietnam were included in the national surface water monitoring network. Information on the contribution of these eight provinces to the national economy presents in Table 2.5-5. Ho Chi Minh City, Binh Duong and Dong Nai are among the most industrially developed provinces in the country. The provinces of Vung Tau, Can Tho, Long An, Tien Giang and Ca Mau, on the other hand, are among the most developed for agriculture and aquaculture. Moreover, population growth rates have been very high in these eight provinces (especially in Binh Duong, at 4.48% year $^{-1}$, and Ho Chi Minh city at 2.84% year $^{-1}$), with an average of 2% year $^{-1}$ (whole country: 1.33% year^{-1}) (VGSO, 2007). Great pressure for socio-economic development may result in a deterioration of water quality of this region. The WQI_B shows thirty sites (60%) classified with poor water quality. Extremely poor water quality was detected in the drainage canal and river sites close to residential areas of Ho Chi Minh City (WQI_B ranging from 6.45 to 18.5), Ca Mau (7.16-12.22), Tien Giang (11.04-21.62), Can Tho (12.44-15.91), Binh Duong (14.61-22.96) and Long An (18.42-21.49). The main pollution problem at these sites were from bacteria (scores from 1 to 8.93), rather than from particulates, organic matter, and nutrients (Figure 2.5-6). The remaining 20 sites in the southern part were further classified into a marginal group (12 sites - 24%), a fair group (5 sites -10%) and a good water quality group (3 sites - 6%).

Table 2.5-5: Contribution of the eight studied provinces in the southern part of Vietnam to the national economy

Economic sector	Contribution to gross product of Vietnam (%)								
	1999	2000	2001	2002	2003	2004	2005	2006	2007
Industry (8 provinces)	53.69	53.00	52.63	51.45	51.14	51.24	51.23	50.70	49.77
Industry (BD, DN, HCM)	36.16	36.17	36.77	36.99	37.15	37.68	38.18	37.97	38.19
Agriculture (8 provinces)	17.32	16.95	15.84	15.83	15.82	15.62	15.79	15.47	15.64
Agriculture (CM, CT, LA, TG, VT)	11.79	11.34	10.33	10.58	10.29	10.16	10.24	9.90	7.80
Aquaculture (8 provinces)	25.67	26.36	27.66	27.04	27.03	26.86	27.99	27.32	26.51
Aquaculture (CM, CT, LA, TG, VT)	23.24	24.22	25.34	24.64	24.36	24.29	25.69	25.03	24.50
Forestry (8 provinces)	10.92	10.16	10.64	10.38	10.03	10.25	10.29	10.31	10.14

Source: VGSO, 2007

Note:

BD: Binh Duong Province, DN: Dong Nai Province, HCM: Ho Chi Minh city, CM: Ca Mau Province,CT: Can Tho city, LA: Long An Province, TG: Tien Giang Province, VT: Vung Tau city

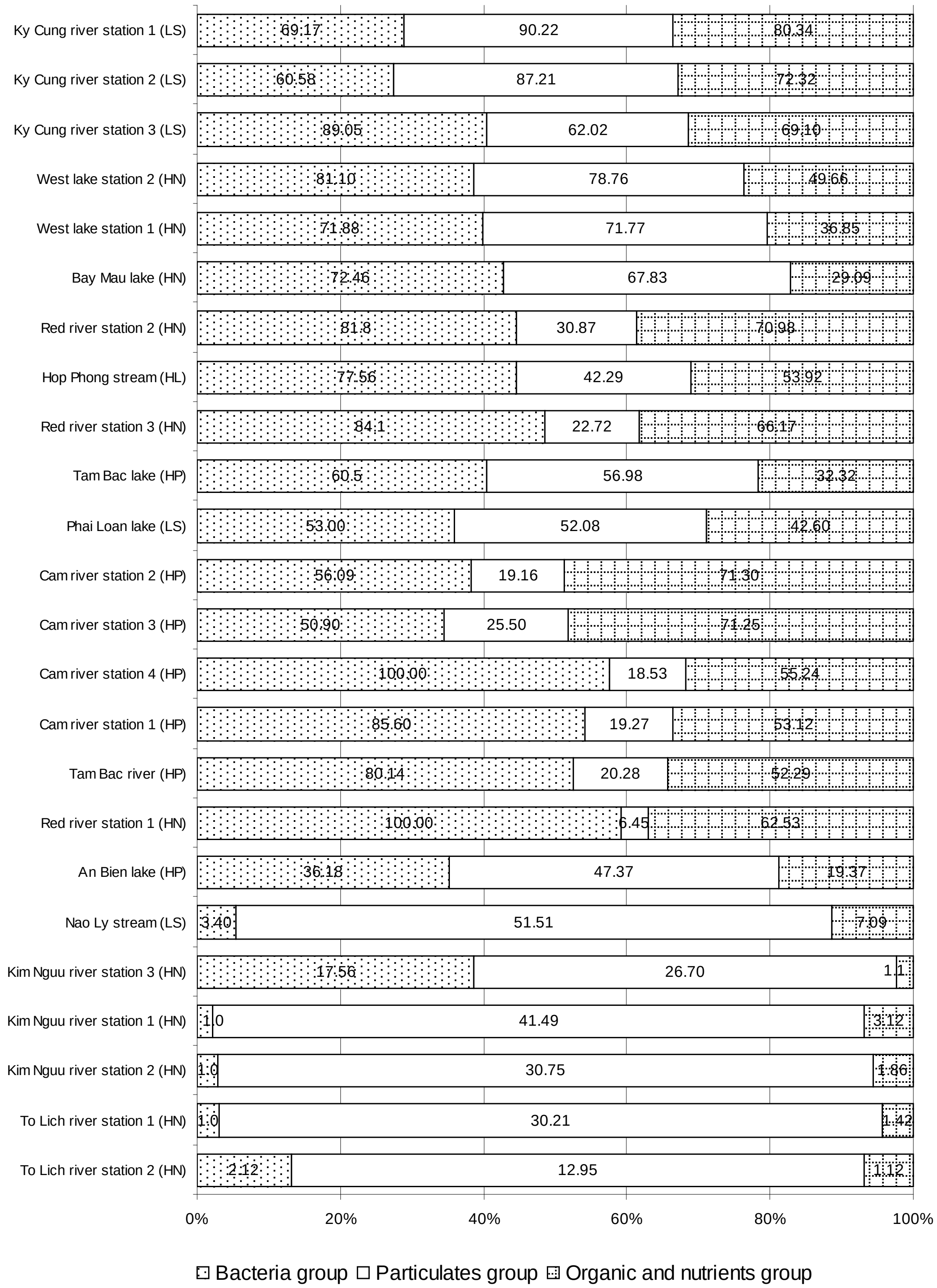

Figure 2.5-4: Identification of water pollutants contributing to water pollution in the northern part of Vietnam, 1999-2007

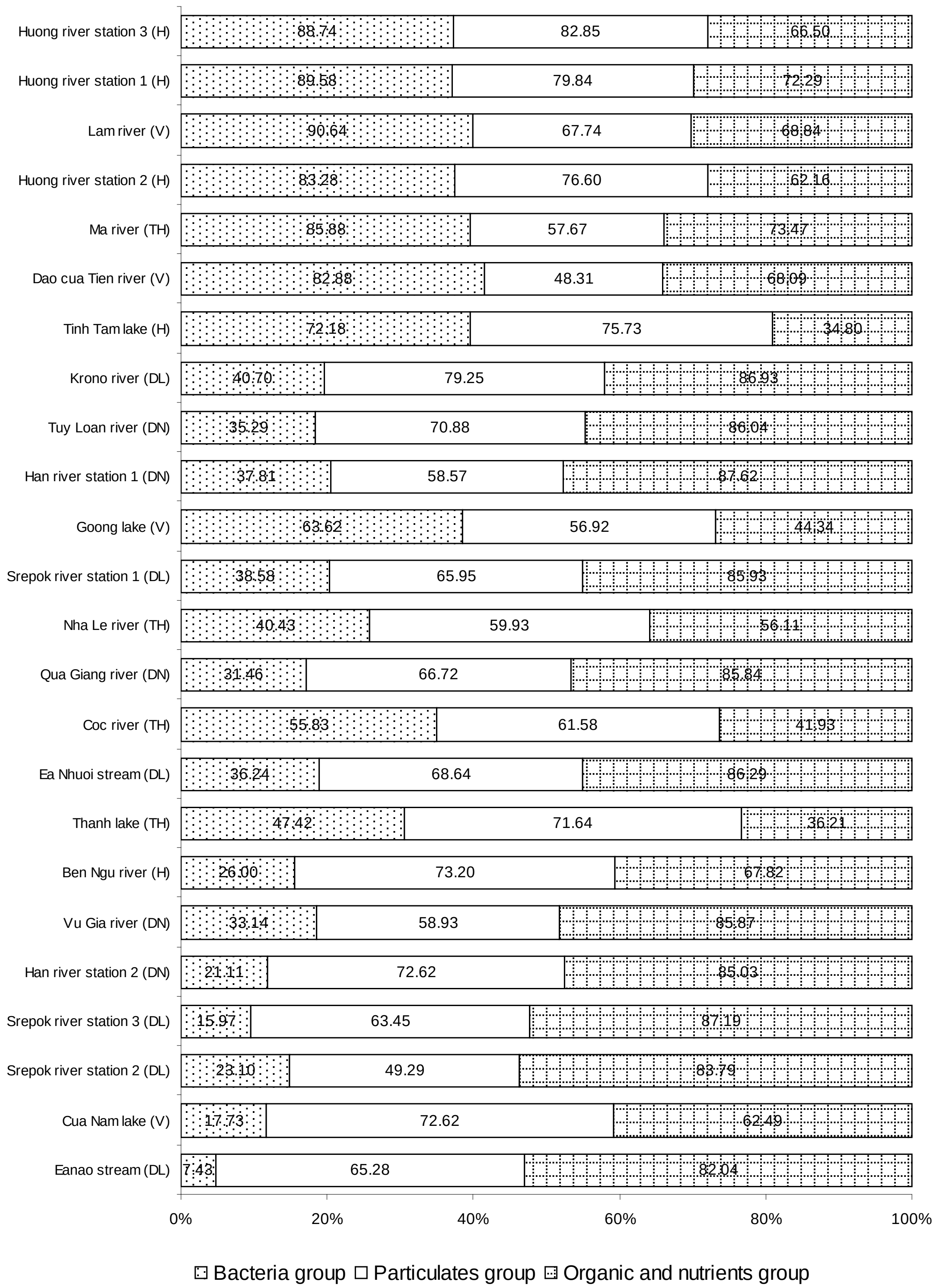

Figure 2.5-5: Identification of water pollutants contributing to water pollution in the central part of Vietnam, 1999-2007

Socio-economic development and water quality trends

Table 2.5-6 gives the summary of trend analysis results of national surface water quality data for each province as well as for the whole country. The results show that water quality over the whole country deteriorated during the period 1999 to 2007 (slope=-2.69 scores yr^{-1}, p=0.0001). This decreasing trend can be also found in Hanoi, Hai Phong, Da Nang, Daklak, Ho Chi Minh, Vung Tau, Binh Duong and Dong Nai cities/provinces (slope=-2.31 to -5.75 scores yr^{-1}, p<0.05). The existing national monitoring network was designed primarily for the purpose of water quality impact assessment. Therefore, the selected monitored cities/provinces are mostly located in the northern, central and southern economic development regions. Most of the water samples were taken from the water bodies receiving discharge from municipal and/or industrial waste water sources. Significant (p<0.05) negative correlations between WQI_B and population growth, industrialization and urbanization were found in the cities/provinces with surface water quality degradation trends (Table 2.5-7).

In Hanoi, there were good to excellent negative correlations between WQI_B and population growth (R=-0.87), industrialization (R=-0.88) and urbanization (R=-0.9). In Haiphong, fair negative correlations between WQI_B and population growth (R=-0.79) and industrialization (R=-0.73) were found. Da Nang and Daklak are considered the most economically developed provinces in the central and central highlands parts of Vietnam. Surface water degradation trends there may be the result of rapid population growth as well as industrialization. Statistical data from 1999 to 2007 (VGSO, 2007) show that population growth rates in Da Nang (2% $year^{-1}$) and Daklak (2.25% $year^{-1}$) were much higher than in other central provinces (Hue had 1.17% $year^{-1}$, Thanh Hoa 0.78% $year^{-1}$) and in the country overall (1.33% $year^{-1}$).

In the southern part of Vietnam, significant good to excellent negative correlations between WQI_B and rapid population growth, urbanization and industrialization clearly indicates the relationship between water quality degradation and human activities in the provinces of Ho Chi Minh, Vung Tau, Binh Duong and Dong Nai. Worse water quality deterioration was found in Binh Duong Province, where population and industrialization increased 4.48% and 29.29% $year^{-1}$ during the study period. These growth rates are the highest in Vietnam. Population growth rates for Ho Chi Minh, Dong Nai and Vung Tau were 2.84%, 1.51% and 2.06% $year^{-1}$, respectively, all higher than for Vietnam as a whole (1.33% $year^{-1}$). The industrial growth rate was relatively high in Dong Nai Province (20.01% $year^{-1}$), compared with the whole country (16.46% $year^{-1}$).

Table 2.5-6: Summary of trend analysis for national surface water quality data, 1999-2007

City/Province	No. of monitoring stations	No. of observations	Basic water quality index (WQI_B) (mean ± S.D)	Trend	
				Slope (scores/year)	p value
Northern part	24	746			
Lang Son (LS)	5	60	53.45±30.26		0.148
Ha Long (HL)	1	41	41.25±20.04	-5.75	0.037
Hai Phong (HP)	7	232	32.50±22.25	-2.31	0.023
Hanoi (HN)	6	241	46.65±25.55		0.323
Hanoi drainage system (HN)	5	172	3.25±2.48	-0.33	0.005
Central part	24	765			
Thanh Hoa (TH)	4	48	49.57±29.17		0.064
Vinh (V)	4	169	58.13±25.88		0.661
Hue (H)	5	210	68.24±22.33		0.057
Danang (DN)	5	155	41.99±29.98	-4.82	0.011
Daklak (DL)	6	183	36.94±30.29	-4.71	0.013
Southern part	50	1914			
Ho Chi Minh (HCM)	10	389	18.49±20.45	-2.44	0.031
Vung Tau (VT)	5	106	49.98±32.09	-5.16	0.001
Binh Duong (BD)	9	202	35.37±29.57	-5.73	0.001
Can Tho (CT)	5	260	18.63±17.02		0.061
Dong Nai (Dnai)	5	83	44.91±31.87	-4.26	0.035
Long An (LA)	6	432	36.01±26.80		0.481
Tien Giang (TG)	5	256	19.12±17.05		0.059
Ca Mau (CM)	5	186	11.53±10.18		0.72
Whole country	98	3425	33.53±29.03	-2.69	0.0001

Table 2.5-7: Pearson's correlations between surface water quality (WQI_B) and population growth, urbanization and industrialization, 1999-2007

Province	Correlation (p value)		
	Population growth	Urbanization	Industrialization
Lang Son	0.978 (0.134)	0.998(0.057)	0.942(0.217)
Hai Phong	-0.790*(0.020)	-0.554(0.154)	-0.729*(0.040)
Hanoi	-0.866**(0.005)	-0.900**(0.002)	-0.882**(0.004)
Thanh Hoa	-0.771(0.229)	-0.431(0.569)	-0.921(0.079)
Hue	-0.649(0.082)	-0.266(0.524)	-0.656(0.077)
Da Nang	-0.853**(0.007)	-0.517(0.189)	-0.790*(0.020)
Daklak	-0.846**(0.008)	-0.138(0.745)	-0.600(0.116)
Ho Chi Minh	-0.705(0.051)	-0.588(0.125)	-0.817*(0.013)
Vung Tau	-0.929**(0.001)	-0.799*(0.017)	0.329(0.427)
Binh Duong	-0.903**(0.002)	0.895**(0.003)	-0.972**(0.000)
Can Tho	-0.695(0.055)	-0.562(0.147)	-0.762*(0.028)
Dong Nai	-0.755*(0.030)	0.143(0.735)	-0.704*(0.041)
Long An	-0.386(0.345)	-0.565(0.145)	-0.067(0.876)
Tien Giang	-0.656(0.077)	-0.664(0.072)	-0.489(0.219)
Ca Mau	-0.143(0.736)	-0.212(0.614)	-0.064(0.880)
Whole country	-0.962**(10.30E-04)	-0.951**(20.90E-04)	-0.966**(90.69E-05)

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

3) Surface water management and WQI applications in Vietnam

The current national surface water monitoring network in Vietnam was established for 17 provinces in 1996 by the Vietnam Environmental Protection Agency (VEPA). This limited system was primarily for impact assessment at selected locations, with collected samples tested against national standards.

Recently, Vietnam's government has authorized a master plan for a comprehensive environmental monitoring network by the year 2020 (known as Decision 16/2007/QD-TTg). According to this plan, the surface water monitoring network will cover all 64 provinces in Vietnam. There will be 414 monitoring sites, a major increase from the 98 present sites. Among them are to be 66 sites for basic surface water quality monitoring and 348 sites assigned to pollution impact assessment (Figure 2.5-2). Additional data will arrive from the provincial level monitoring network and environmental projects.

Monitoring engenders vast data; the challenge of optimizing its use is met by effective tools described here, which can easily and rapidly interpret large amounts of water quality data into understandable information on surface water conditions for policy makers and the public, who all have a stake, as well as for water management professionals.

The two newly developed water quality indices can serve as such tools. The WQI_B can be effectively used to evaluate the spatial and temporal variations of surface water quality, to identify water pollutants and to reflect the impacts of socio-economic development on surface water quality. The WQI_O can provide additional information, particularly on toxic substances contributing to water pollution. Together the indices can well serve the objective of informing policy decisions for sustainable water resources management in Vietnam.

Conclusions

Two types of water quality indices were developed for the purpose of surface water quality evaluation in Vietnam. The basic water quality index (WQI_B) can be effectively used to evaluate the spatial and temporal variations in surface water quality as well as to identify water pollutants. The overall water quality index (WQI_O) can provide additional information, especially on the contribution of toxic substances to water pollution.

Surface water quality in the northern and central parts was poor with organic matter, nutrients and bacteria, while water in the southern part was mainly polluted by bacteria. Drainage systems, lakes and stretches of rivers close to urban areas had extremely poor water quality. This raises alarms about the impacts of discharging untreated wastewater on the quality of surface water in large urban cities. Analysis of water quality trends shows some possible negative impacts of socio-economic development on surface water quality in the provinces studied.

The implementation of water quality indices can well serve the objective of sustainable water resources management in Vietnam.

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2.6 Development of Water Sustainable Index: A Case Study in Bangkok, Thailand

Proposed Water Sustainability Index: A Case Study of Bangkok City

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Abstract

This study aims to propose an indicator for urban sustainable water management by aggregation from 3 aspects, environment, economic and social. Thirteen sub-indices derived from those 3 aspects were used to determine the sustainability of water management of Bangkok city during the year 1999-2009. General water quality index and percentage of parameters (BOD, DO, NH_3, NO_3^-) that had not deviated from surface water quality standards were represented as indicators for environment aspect. Water use efficiency and water infrastructure requirements were used as indicators for the economic aspect. Human health impact, water supply accessibility, waste water treatment coverage area, population served by the wastewater treatment system, and percentage of treated wastewater volume were indicators for the social aspect. Results show that water sustainability index (WSI) calculated from 13-subindicators was 54.8 for all aspects combined, where the economic sector had highest score of 71.1, followed by environment and social aspects, respectively. To forecast water sustainability management from the Bangkok development plan in the next 10 year cycle, eight sub-indicators were selected. It was found that WSI for the year 1999-2009 was 55.1, and it was 87.7 in the year 2010-2019. The improvement of WSI in the future was likely due to improvements in water quality in many water bodies that met planned required surface water quality standards. However, this task will challenge the Bangkok Metropolitan Administration (BMA) because the wastewater treatment plant coverage still will not cover total area of Bangkok in the next 10 years.

2.6.1 Introduction

Water is important for all forms of life. Its quality depends on intended use of the water, influenced by economic, technological resources, politics and may also change as a result of development. As the high growth of population and the development of economic domains such as agriculture, industry, commercial business, and services have increased, water demand has also increased drastically, whereas access to freshwater is becoming more limited. Increasing urbanization has also resulted in an increase in water demand. To sustain urban water management, the planning and management of the environment and provision of basic needs to people living in a city are necessary.

Sustainable development was first introduced at the Earth Conference on Human Environment in Stockholm in 1972. The idea calls on the world to consider the human impact of the exploitation of natural resources within limitations of the Earth. Following the UN conference on Environmental and Development (UNCED) in Rio de Janeiro, Brazil in 1992, the concept became globally recognized. The quantitative assessment of sustainability requirement for urban regions can be used for planning, initiating implementation, and monitoring progress toward sustainable cities (Walsh et al., 2006). Hence sustainable development indicators (SDIs), which are designed to integrate environment, economic and social aspects, are normally used as a tools for sustainable development of a city. Their effectiveness depends on how they are applied. Such indicators are primarily used in performance monitoring and reporting to permitting authorities, benchmarking, and planning. Such applications are presumably just as important in supporting sustainable development, but there are few or no documented examples of them in the water sector (Palme and Tillman 2007). Water sustainability assessment was studied in some areas such as Vietnam (Bolay et al., 1997), China (Eastcott et al., 2003), Brazil and Scotland (Ioris et al., 2007), Sweden (Palme & Tillman, 2007), and Canada (Policy Research Initiative, 2007).

In response to the planned implementation of the world summit on sustainable development for the proportion of people who are unable to reach, or to afford, safe drinking water by the year 2015 (The World Bank, 2001), Thailand has progressed their water resource management and raised the Water Vision and Policy for Water Improvement. The concerned institutions and agencies have tried to solve issues with water shortages and water deterioration. The Chao Phraya River or "King River" is the most important river in Thailand. It has a long history of Thai settlement due to the country's dependency on agriculture. The lower part of the Chao Phraya River passes through Bangkok, the capital city of Thailand. Thai people settled along both sides of the Chao Phraya river bank and along the both sides of several canals nearby. Most canals are connected not by natural means, and are built up for irrigation and transportation purposes. From increasing urban population and ineffective land utilization, there is a high intensity of houses on the inside Bangkok making for congested community areas. Moreover, agricultural land was converted to industrial and commercial uses. Because of this, the water quality was deteriorated and is limited to beneficial uses. However, the quantification of social and economic aspects related on water quality management was limited. Therefore this study has attempted to apply and develop WSI for Bangkok city. In addition, the WSI for the next 10 years was also investigated to evaluate sustainable water development, and to use this as a guideline for other cities.

2.6.2 Materials and methods

1) Background data

The background data during the year 1999 – 2019 in this study include environmental, economic and social information derived from many organizations. Data during the 2010 – 2019 years were derived from development plans or calculations from previous data. Information details are shown in Table 2.6-1.

Table 2.6-1: Detailed information on environment, economic and social

Category	Parameter	Source of Data
Environment	Water quality	DDS
	Numbers of population	BMA
	Population density	NESDB
	Water supply production	MWA
	Surface water quality standard	PCD
	Water quality index	PCD
Economic	GDP	NESDB
	Water demand	MWA
	Budget for water management	BMA
Social	Wastewater treatment capacity	DDS
	Population served by potable water supply	BMA
	number of reported waterborne disease and illness	MPH

Note: BMA : Bangkok Metropolitan Administration

DDS : Department of Drainage and Sewerage

MWA : Metropolis Waterworks Authority

PCD : Pollution Control Department

NESDB : National Economic and Social Development Board (NESDB)

MPH : Ministry of Public Health

2) Numbers of population

The population numbers during the year 1999-2009 were calculated for growth rate. Then, the percentage of the growth rate was used to calculate the population numbers during the year 2010-2019.

3) Wastewater production, water consumption and water supply production

Wastewater production was calculated by using the data from Pollution Control Department (PCD) as shown in Table 2.6-2. The amount of water consumption was estimated by assuming the 80% of water consumption will be wastewater. Data from Metropolis Waterwork Authority (MWA, 2009) provided water supply production which deducted the loss of water 39.4- 29.2 % during the year 1999-2009. The amounts of water supply production and the loss of water during the year 2010-2018 used the data of the year 2009.

Table 2.6-2: **Wastewater production**

Year	1999-2001	2002 - 2006	2007 - 2011	2012 - 2016	2017 - 2018
Wastewater production (L/capita-day)	204	229	259	295	336

Source: http://www.pcd.go.th/info_serv/water_wt.html

4) Water Quality

The annual water quality of lower Chao Phraya river and canals in Bangkok was evaluated by modifying the water quality index of PCD as shown in Eq.(1). Prior to using this equation, each water quality parameter has to convert to each sub-index as shown in Figure 2.6-1.

$$WQI = \sqrt[6]{(pH)(DO)(NO_3 - N)(PO_4)(BOD)(SS)} \qquad (1)$$

The description of water quality from the final score can be compared to Thailand surface water quality standard as shown in Table 2.6-3.

Table 2.6-3: WQI and water quality classification

WQI range	Description	Surface water class	Beneficial uses
91-100	Very good	1	Use for ecosystem conservation
71-90	Good	2	Use for consumption, aquatic organisms of conservation, fisheries and recreation
61-70	Medium	3	Use for consumption, agriculture
31-60	Poor	4	Use for industry
0-30	Very poor	5	Use for navigation

BMA had set strategic development plans to develop Bangkok as a sustainable metropolis. One of the strategic plans was to increase the efficiency of water quality management. Water quality for canals in wastewater treatment service areas by maintained water quality in targeted canals: DO concentration greater than 2mg/L in the year 2012 and 2.5 mg/L in the year 2020 and recovered water quality in targeted canals: DO concentration greater than 1.5 mg/L in the year 2012 and 2.0 mg/L in the year 2020 (Strategy and Evaluation Department, 2008).

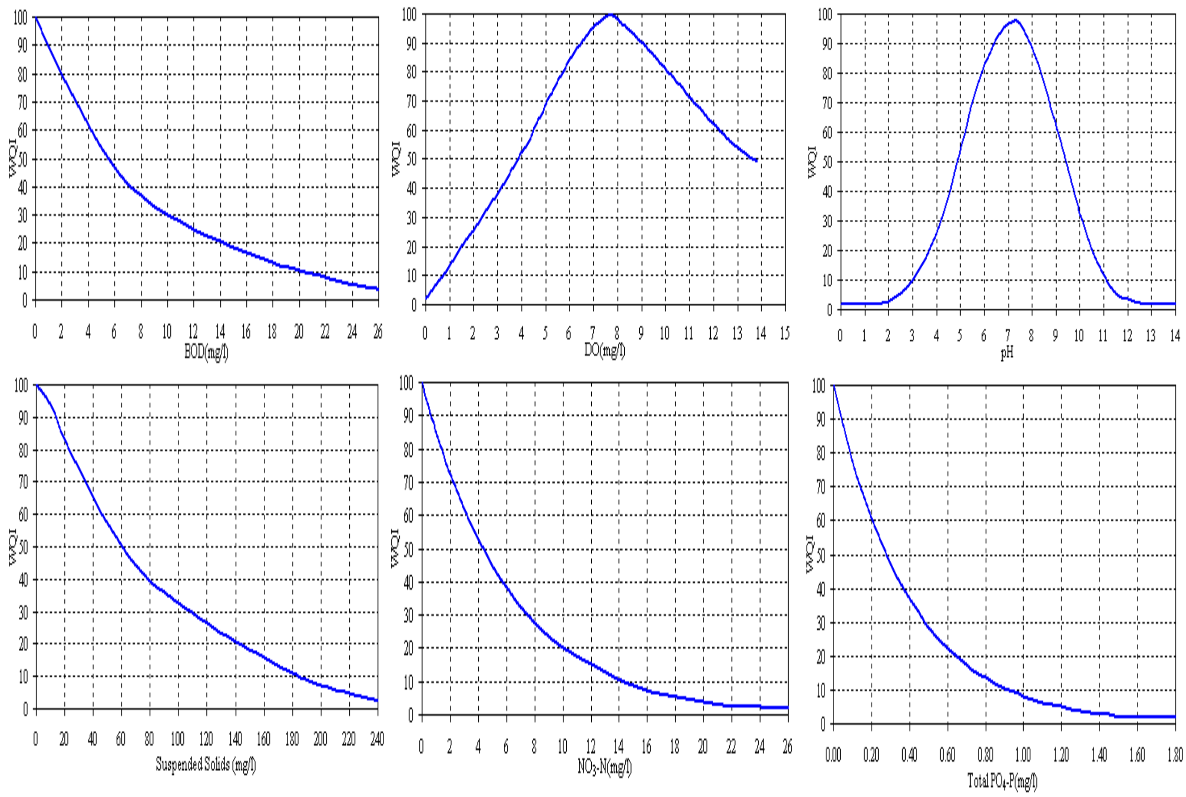

Figure 2.6-1: Sub-index function of each parameter

<u>Water Sustainability Index Calculation</u>

Water sustainability index (WSI) can be divided into three parts: environment, economic and social. Due to the limited availability of Bangkok information, this study chose the various methods for calculation individual indicators as summarized in Table 2.6-4 to Table 2.6-6.

Once the indicator scores are calculated, component-level scores are determined by taking the average score of the three dimensions that make up that component. The final index score is determined using the following equation:

$$WSI = \frac{\sum_{i=1}^{n} S_i}{3}$$

where: S_i refers to component i of the index for environment, economic and social.

Table 2.6-4: Proposed environmental indicators

No	Description	Reference
1	WQI = $\sqrt[6]{(pH)(DO)(NO_3-N)(PO_4)(BOD)(SS)}$	Adapted from PCD
2	percentage of BOD that not deviated from surface water class 4	
3	percentage of DO that not deviated from surface water class 4	
4	percentage of NH_3 that not deviated from surface water class 4	
5	percentage of NO_3^- that not deviated from surface water class 4	

Table 2.6-5: Proposed economic indicators

No	Description	Reference
1	$\text{Wateruse Efficiency} = 100 - \left(100 \times \frac{(GDP_2 - GDP_1)}{GDP_2}\right) - \left(100 \times \frac{(demand_2 - demand_1)}{demand_2}\right)$ GDP_2 = catchment gross domestic product of the current period GDP_1 = catchment gross domestic product of the previous period $demand_2$ = water demand from ground and surface water for the current period $demand_1$ = water demand from ground and surface water for the previous period	Adapted from Ioris et al.(2007)
2	Water Demand (I_D) = $\frac{t_{100}}{50} \times 100$ If $t_{100} \geq 50$, then I_D *ID* = 100 If $t_{100} = 0$, then I_D *ID* = 0 If $50 > t_{100} > 0$, then calculate I_D *ID* using the above equation $t_{100} = \frac{\log FV - \log PV}{\log(1 + r)}$ FV = number of people that can be served at 100% capacity of existing system* PV = number of people currently being served by existing system r = annual rate of population growth **A constant per capita water use is assumed; however, significant known trends can be factored in.*	Policy Research Initiative (2007)
3	% Budget for water management = $\frac{100*(\text{Budget for water management})}{\text{Total budget for DDS office}}$	

Table 2.6-6: Proposed social indicators

No	Description	Reference
1	Human health impact, $H_I = (1 - W) \times 100$ W = number of reported waterborne disease and illness cases/1000 people. If W = 0, then H_I = 100 If W ≥1, then H_I = 0 **Note:** the waterborne diseases(Diarrhea, Typhoid, Shigellosis, Cholera)	Policy Research Initiative (2007)
2	Water supply accessibility, $H_A = 100 - (\frac{150 - y}{150 - 50} * 100)$ *y* = amount of accessible potable water available per person per day (L/cap/day) If *y* ≥ 150, then H_A = 100 If *y* ≤ 50, then H_A = 0 If 150 > *y* > 50, the calculate H_A using the above equation	Policy Research Initiative (2007)
3	Percentage of coverage area served by centralized wastewater treatment	
4	Percentage of population served by centralized wastewater treatment	
5	Percentage of wastewater volume being treated	

2.6.3 Results

Bangkok occupies an area of about 1,568 km^2 and the registered population is about 5.7 million. The great number of net immigrants is an important factor contributing to rapid growth of the Bangkok population, such that it has reached 6.3 million in the year 2008. The numbers of population from registered people in each district of the Bangkok area in the year 2002 and the forecast numbers of population in the year 2017 are shown in Figure 2.6-2. It shows that the numbers of population decrease in the middle of the city and tend to increase in the outer areas. The expansion of population not only occurred in the outer area of Bangkok but also took place in five provinces surrounding Bangkok.

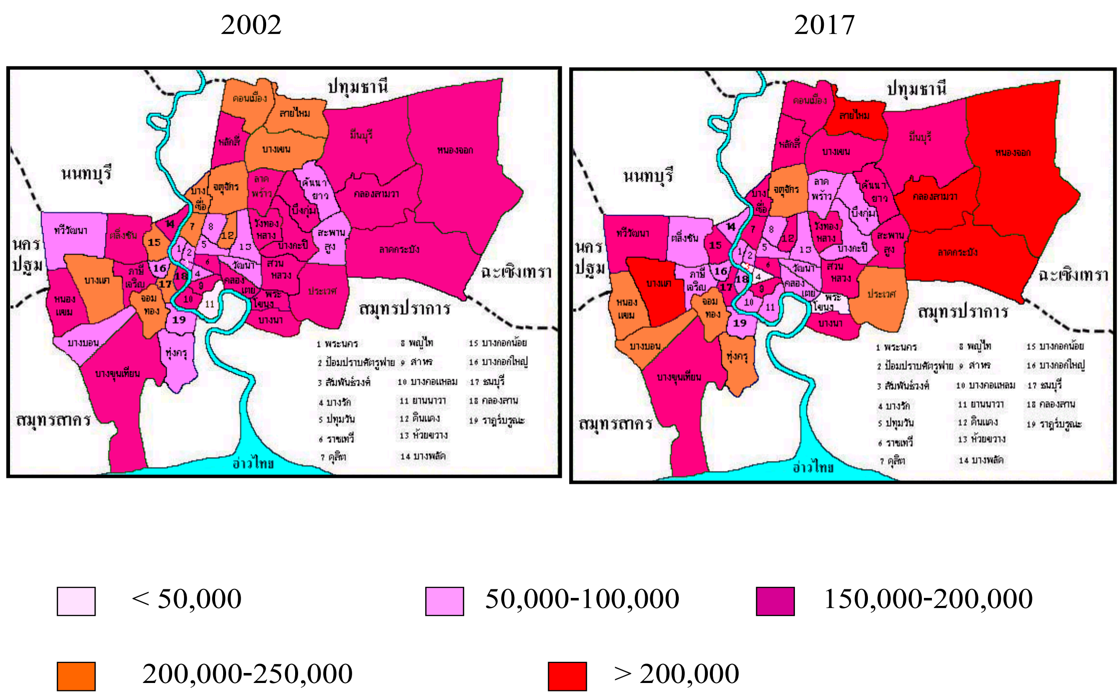

Figure 2.6-2: Population of Bangkok in 2002 and forecasted in 2017

Figure 2.6-3 shows the numbers of population, amount of water supply production, water use and wastewater production. The water supply production shows a trend of rapidly increasing year by year. The figure shows a large gap between water supply production and water consumption. This seems to indicate that the water supply is sufficient for the Bangkok Metropolis. However, the Metropolitan Waterworks Authority (MWA) produces water based on the demand from the public in BMA, Nonthaburi and Samut Prakarn Provinces. Raw water for water supply production is derived from the upstream of Chao Phraya River. It is conveyed through constructed canals (Klong Prapa) which started from Pathum Thani (96 km from the river mouth) to prevent pollution from Bangkok and reduce salt intrusion. Then, the water is transported to the Bang Khen, Sam Sen and Thonburi water treatment plants. Due to the rapid urbanization, some areas in the western part of Bangkok use the water from Mae Klong River which has a better quality than the Chao Phraya River. The water is conveyed through 107 km to the Mahasawasdi water treatment plant. Raw water is treated before being distributed to the public, to achieve recommended water quality according to the World Health Organization (WHO) guidelines. The Gross Provincial Product (GPP) of Bangkok during the year 1999-2008, and the forecast from the Bangkok administration plan at the rate of 50% is plotted in Figure 2.6-4. To determine centralized wastewater treatment capacities for the coverage area, volume of wastewater treated, the existing wastewater treatment, and future plans were sufficient, these were investigated as shown in Figure 2.6-5.

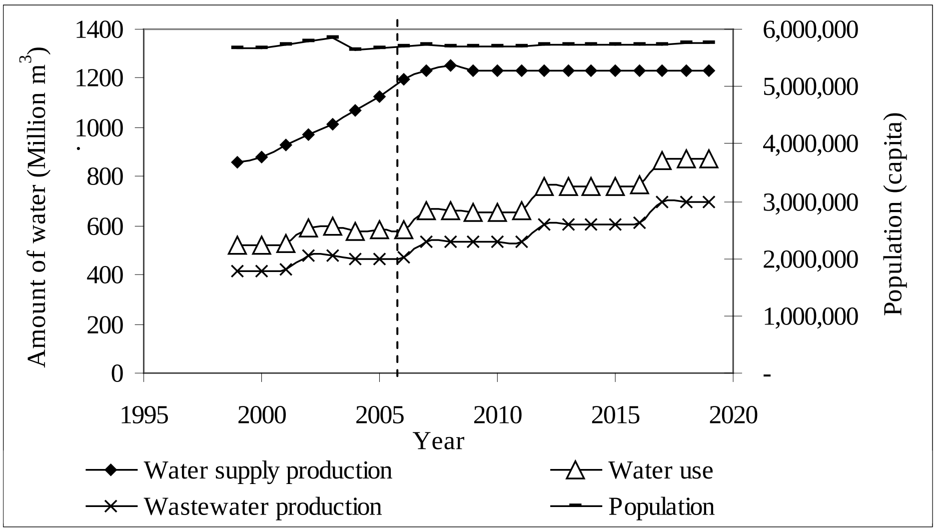

Figure 2.6-3: Amount of water and population in Bangkok city.

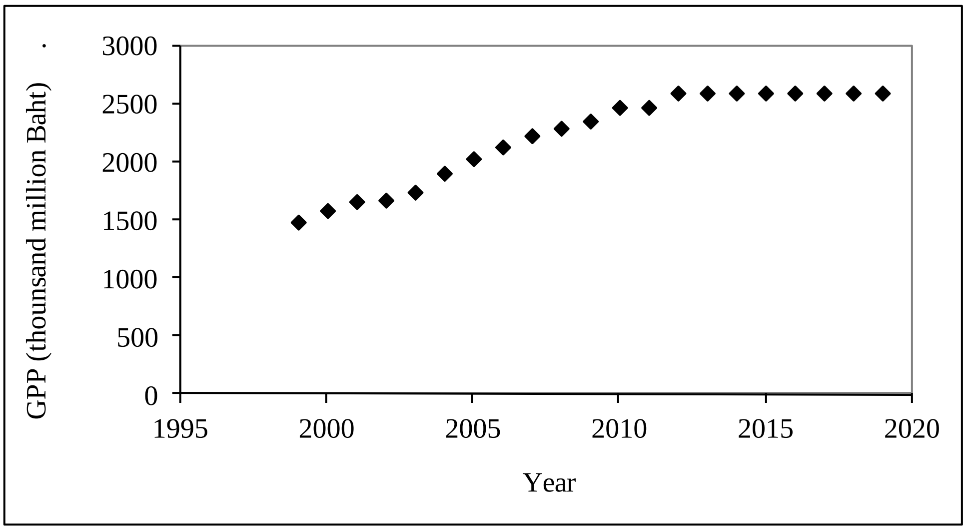

Figure 2.6-4: Gross Provincial Product of Bangkok city

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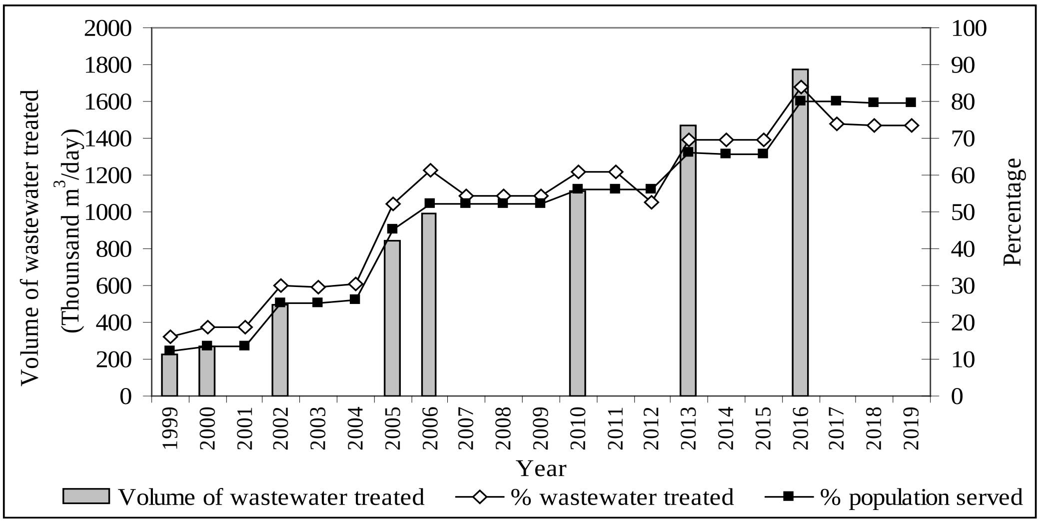

Figure 2.6-5: Capacity of wastewater treatment

Results from the determination of sustainability indicators of environment, economic and social using 13 sub-indicators and 8 sub-indicators and the average WSI in the year 1999-2009 and the next 10 year (2010-2019) are shown in Table 2.6-7. Figure 2.6-6 shows the WSI of each year.

The average WSI values during the year 1999-2009 are around 54.8%. This reduced sustainability management on water in Bangkok city is due to low management in social and environmental aspects. Bangkok is facing various social challenges such as rapid urbanization. The population of Bangkok presently is close to 7 million by registered records, or about 10 million including the daytime population who commute from the vicinity and nearby provinces. This high numbers of population in the city is currently faced with unavoidable water pollution in the river and canals. Most water quality problems relate to DO depletion or excessive organic loads, and high loading of ammonia and coliform bacteria primarily from domestic sources. The major impacts of water pollution are the deterioration of the water supply source. BMA has realized the importance of solving these problems and tried to improve people's water quality, together with the environment, by installation of new centralized wastewater treatment plants and also set up water quality targets to achieve a water class of 4. This makes the average WSI value rapidly increase to 87.7 % during the year 2010-2019. Despite the promulgation of laws and setting up of governmental agencies, the control of environmental degradation and enforcement of legislation have been slow due to budget and skilled manpower constraints (Sim & Balamurugan, 1991; Bolay et.al, 1997).

Table 2.6-7: Percentage of range and average values of sub-indicators for the year 1999-2009 and 2010-2019

Sub-indicators			Average (range) values	
			1999-2009	2010-2019
Environment	1. WQI	Canals	42.8 (44.6-47.1)	-
		Rivers	59.4 (55.7-63.3)	-
	2.% of BOD not deviate from standard	Canals	2.0 (0.0-8.0)	100 (100.0-100.0)
		Rivers	33.0 (0.0-100.0)	-
	3. % of DO not deviate from standard	Canals	43.0 (17.0-58.0)	100 (100.0-100.0)
		Rivers	92.0 (11.0-100.0)	-
	4. % of NH_3 not deviate from standard	Canals	9.0 (0.0-25.0)	-
		Rivers	91.0 (60.0-100.0)	-
	5. % of NO_3 not deviate from standard	Canals	100 (100.0-100.0)	-
		Rivers	100 (100.0-100.0)	-
	Average		57.5	100.0
Economic	6. Wateruse efficiency		95.2 (87.7-100.0)	99.0 (95.3-100.0)
	7. Wateruse efficiency		100 (100.0-100.0)	100 (100.0-100.0)
	8. Budget for water management		18.0 (7.6-32.2)	-
	Average		71.1	99.5
Social	9. Health impact		0.0 (0.0-0.0)	
	10. Water supply accessibility		100 (100.0-100.0)	100 (100.0-100.0)
	11. % of coverage area		8.1 (2.3-12.2)	17.5 (12.2-20.1)
	12. % of population served		33.7 (13.6-52.2)	68.5 (13.6-79.7)
	13. % of wastewater volume treated		38.4 (18.7-54.4)	68.8 (54.4-73.6)
	Average		36.0	63.7
WSI for 1-13 subindicators			54.8	-
WSI for 2, 3, 6, 7, 10, 11, 12, 13			55.1	87.7

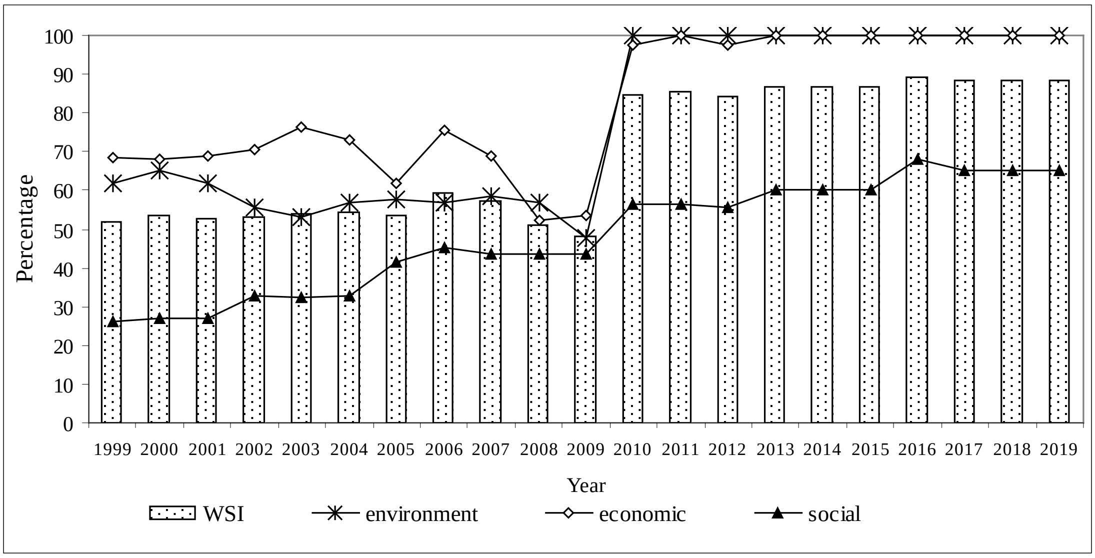

Figure 2.6-6: Environment, economic and social sub-indicators and WSI in the year 1999-2019

Sujaritpong & Nitivattananon (2009) reported that the measures for enhancing wastewater management can be done by tax incentives, which will improve wastewater management by reducing operation and maintenance costs. Effluent discharge fees can be levied on loss of quantity, which may have the duel impact of reducing discharge volume and encouraging reuse programs. Awareness campaigns should be conducted in order to communicate with, and mobilize, residents. Some examples of awareness campaigns would be initiating demonstration projects and rewarding good practices and other stimulations for the public.

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3 Capacity Building

3.1 Internship Program

The International Environmental Research Center at the Gwangju Institute of Science and Technology (GIST), Korea, operated and funded APN members and their graduate students to attend an internship program at GIST, twice a year for a 4 month period. This program provided an opportunity for participating APN members and their students to conduct research and undergo studies for a semester at GIST, which expanded their technical knowledge and skills on sustainable urban water quality management. Since 2009, there were a total 8 APN interns (2 from Cambodia, one each from Thailand and Indonesia and 4 from Vietnam) who participated:

Names	Affiliations
Mr. San Vibol	Royal University of Phnom Penh, Cambodia
Mr. Piyanat Sawat-Uea	King Mongkut's University of Technology Thonburi, Thailand
Ms. Pham Thi Diem Phuong	Ho Chi Minh City University of Technology, Vietnam
Ms. Huynh Thi Thanh Thao	Ho Chi Minh City University of Technology, Vietnam
Ms. Jkunthy Sok	Caller at New World Institute, Cambodia
Ms. Deby Fapyane	Airlangga University, Indonesia
Mr. Lam Thanh Phan	Ho Chi Minh City University of Technology, Vietnam
Ms.Phuong Thi Thuy Do	Ho Chi Minh City University of Technology, Vietnam

3.2 APN Meetings

Since 2009, there have been a total of 5 APN meetings organized at different Southeast Asian countries as displayed below. The main objectives of these meetings were to disseminate our research outcomes, as well as to bring together local scientists and policy makers and our APN members to discuss emerging urban water quality issues with a focus on developing research tools and capacity building program for sound management of urban water quality.

Years	Schedules	Meeting venues
2009	November 10-11	1st APN meeting in Bangkok, Thailand (1st Strategic Meeting of APN Members for the Asia Pacific Network Project)
2010	July 27-28	2nd APN meeting in Ho Chi Minh City, Vietnam (Strategic Policies for Sustainable Urban Water Quality Management in the Southeast Asia Region)
	November 15-16	3rd APN meeting in Manila, Philippines

		(Sustainable Urban Water Quality Management in Southeast Asian Countries)
2011	May 1-2	4th APN meeting in Bali, Indonesia (Development of Strategic Plan for Sustainable Urban Water Quality Management in Southeast Asia)
	Dec. 20-21	5th APN meeting in Bangkok, Thailand (Sustainable Urban Water Quality Management in Southeast Asia: Implementation of Research Development Tools)

4.0 Urban Water Database

This database (www.apn-seawed.com) was constructed as one of outcomes from this collaborative research. The main objective is to benefit both scientists and policymakers in Southeast Asia for their research and decision making process on policies related to sustainable urban water quality management. The building of this database was possible by the financial support from Asia-Pacific Network for Global Change Research (APN) and by the hard work of all participating project members from Cambodia, Indonesia, Thailand, Vietnam, Korea and Taiwan. This database is composed of six sub database categories, namely, climatic, demographic, geographic, hydrological, industrial, and water quality data. This database is currently focusing on four Southeast Asian countries: Cambodia, Indonesia, Thailand and Vietnam. Query searches for data will be displayed in a table form with mean, median, standard deviation and maximum and minimum values. These results can be downloaded by the user in a simple spreadsheet format.

An additional two WQI systems, including a manual and automatic computation of WQI were constructed. WQI obtained from an automatic computation can be calculated based on the calculation methods applied in each country namely, Indonesia, Thailand and Vietnam. Additionally, several water quality parameters are also available in the constructed database such as pH, turbidity, TDS, TSS, DO, BOD, COD, NO_2^-, NO_3^-, PO_4^{3-}, TP, TN, TCB, and FCB that are used as input parameters for WQI computation. While manual computation of WQI was constructed to allow the users to calculate WQI based on their existing data.

This database is dynamic and is constructed for continual update by the managing administrators of the APN project group. This feature is important to allow for timely, certified data from each country to amend the current database in the future years.

5.0 Conclusions

Several analytical tools related to urban water quality including risk assessment of metals and pathogens, analyses of urban water quality management, prediction of water quality using SWAT model, identification of pollutants by water quality indexes, and water sustainability index were developed. The conclusions of each study are as follows:

1) Risk assessment of metals

The general water characteristics and metal concentrations in the rivers were found to be site specific. The results of dissolved metal concentrations exceeding the range of background concentrations clearly indicated that human activities brought contamination by metal pollution to each river studied. The total concentrations of Al, Fe, and Mn, which much affect drinking water aesthetics, were found in high concentrations for all four rivers. Overall, the total metal concentrations in the Tonle Sap-Bassac Rivers and the lower Chao Phraya River were significantly higher in the wet season than in the dry. The elevated metal contents in the wet season likely arrive from such anthropogenic sources as agricultural activities, wastewater treatment systems, and road dust. Risk evaluation of metal toxicity using CCU clearly indicates the probability of additive and negative effects of metal pollution to aquatic organisms in the study areas. The non-priority pollutant Al was found to be the element contributing the highest percentage to total CCU scores. The existing knowledge of trace metals in the river waters of SEA is, at present, too incomplete. More research into the processes that control the distribution of trace metals in river water, as well as into the sources of river system metal pollution, should be undertaken to provide a sufficient understanding of trace metal behavior in the rivers of SEA.

2) Pathogen risk assessment

In conjunction with sampling for chemical parameters, surface water samples were collected from Vietnam, Indonesia, Cambodia, and Thailand associated with large urban areas in each respective country. Water samples were processed to enumerate *Escherichia coli* and were further characterized using PCR to detect the presence of specific virulence genes. Analyzing the four countries together, the approximate mean log CFU/100 ml for *E. coli* counts in the dry season were log 4.3, while counts in the wet season were log 2.8. Of the 564 *E. coli* isolates screened for the presence of pathogenic genes, 5.3% possessed at least one virulence gene. The most common pathogenic isolates found were Shiga toxin producing strains. These results reinforce the importance of monitoring urban surface waters for fecal contamination and that *E. coli* in these environments may act as opportunistic pathogens. Such survey information is critical in establishing proper water quality parameters and may better predict the impact human pathogens may have on water usage.

3) Analyses of urban water quality management

The state of urban water quality many cities in South East Asian presently face are various typical challenges for developing countries — rapidly and uncontrolled population growth, lack of domestic and industrial waste water provision, political will of top policy makers, public awareness, capacity building among others. In addition, appropriate water quality regulation is one of the most difficult challenges in the area of environmental policy as there are always gaps for effective implementation which require more attention from concerned stakeholders. This paper provides an overview on the effectiveness of urban water quality management in selected case in Bandung, Bangkok, Ho Chi Minh and Phnom Penh. Furthermore, SWOT analysis was employed to determine strengths, weakness, opportunities and threats to urban water quality management at the current condition, and to come up with urgent strategies to improve future urban water quality management.

4) Prediction of water quality using SWAT model

The modeling study needed to be enhanced by collecting more watershed-associated data, and using high-resolution Hydrology Response Unit (HRUs) in the SWAT model. As well, the is a need of more suitable monitoring stations for water quality and quantity where the tidal effect on monitoring station should be insignificant. These effects will promise more accurate and liable modeling results and address predictive information for effective water resources management schemes. In addition, there are substantial uncertainties to predict precipitation and temperature in the future because these models did not consider a feedback process between climate and land surface. It will be a better approach if a global-scale climate change model is replaced with a regional model, considering land use change and its impact on water quality. This will allow for more realistic future climate data as improve well water quantity and quality prediction.

For BMP implementations, there may be some consideration for costs to install and manage structural BMPs for a better assessment. Furthermore, it is necessary to optimize types and place of BMPs in the watershed, attempting to minimize costs and maximize the performance of BMPs. These results provide a preliminary study, showing brief modeling results by coupling the SWAT model with GCM model as and neural networks. It is hoped that this could be a framework for further dynamic modeling works.

5) Identification of pollutants by water quality indexes

Two types of water quality indices were developed for the purpose of surface water quality evaluation in Vietnam. The basic water quality index (WQI_B) can be effectively used to evaluate the spatial and temporal variations in surface water quality as well as to identify water pollutants. The overall water quality index (WQI_O) can provide additional information, especially on the contribution of toxic substances to water pollution.

Surface water quality in the northern and central parts was poor, with organic matter, nutrients and bacteria, while water in the southern part was mainly polluted by bacteria. Drainage systems, lakes and stretches of rivers close to urban areas had extremely poor water quality. This raises alarms about the impacts of discharging untreated wastewater on the quality of surface water in big cities. Analysis of water quality trends shows some possible negative impacts of socio-economic development on surface water quality in the provinces studied. The implementation of water quality indices can well serve the objective of sustainable water resources management in Vietnam.

6) Water sustainability index were also developed.

This study aims to propose an indicator for urban sustainable water management by aggregation from 3 aspects, environment, economic and social. Thirteen sub-indices derived from those 3 aspects were used to determine the sustainability of water management of Bangkok city during the year 1999-2009. General water quality index and percentage of parameters (BOD, DO, NH_3, NO_3^-) that had not deviated from surface water quality standards were represented as indicators for environment aspect. Water use efficiency and water infrastructure requirements were used as indicators for the economic aspect. Human health impact, water supply accessibility, waste water treatment coverage area, population served by wastewater treatment system and percentage of treated wastewater volume were used as indicators for the social aspect. Results show that water sustainability index (WSI) calculated from 13-subindicators was 54.6 for all aspects combined which the economic sector having the highest score of 70.49, followed by environment and social aspects, respectively. To forecast the water sustainability management from the Bangkok development plan in the next 10 years, eight sub-indicators were selected. It was found that WSI for the year 1999-2009 was 55.1, and was 87.7 in the year 2010-2019. The predicted improvement of WSI in the future was likely caused by improvement in water quality for the water bodies due to plans to meet surface water quality standard requirements. However, this task will challenge the Bangkok Metropolitan Administration (BMA) because wastewater treatment plants still could not cover total area of Bangkok within the next 10 years.

Additional Outcomes and Conclusions:

Regarding capacity building, eight graduate students as well as APN members from four participating countries were offered an opportunity to attend an internship program will full support at Gwangju Institute of Science and Technology in Korea. With this participation, their skills on water quality sampling, analysis and management had been significantly improved. Furthermore, a series of APN meeting were organized at different Southeast Asian cities to provide opportunities for both local, and APN project, scientists and policy makers to exchange their ideas and experience on development of analytical tools, as well as sustainable management of urban water quality.

Finally, this project was able to collect as much as possible data related to urban water quality management ,and compiled them in a systematic way for benefit of both local scientists and policy makers in Southeast Asia for their future research work and decision making processes.

6.0 Future Directions

6.1 Developed analytical tools for urban water quality management will be tested at Bangkok Metropolitan Administration and later expand its implementation to Environmental Protection Agency, West Java, Indonesia, and other SEA countries

6.2 Current database will be expanded to cover all 10 Southeast Asian nations. New functions for data interpretation will be added

6.3 Further developing SWAT as a tool to predict urban water quality as a results of human activities as well as climate should be conducted

6.4 Capacity building of local officers to use developed analytical tools as well as database should be organized for all 10 SEA countries in a format of workshops.

6.5 Philippines, Malaysia and USA will be invited to join the 2nd phase with focusing on implementing of developed analytical tool

6.6 Scientific observation on the effects of pollutants in the rivers to ecosystems are recommended to be conducted through an ecological health risk assessment study

6.7 Scientific-proved identification of the sources for contributing pollutants into the rivers should be promoted

Appendix

Conferences/Symposia/Workshops

1st Strategic Meeting of APN Project Members (ARCP2009-13NMY-Sthiannopkao)

"Collaborative research on sustainable urban water quality management in Southeast Asian countries: analysis of current status (comparative study) and develop a strategic plan for sustainable development"

Participants: APN project members (Cambodia, Indonesia, Thailand, Vietnam, Korea)
Meeting venue: Service Building, 6th Floor, Room # 606, Chulabhorn Research Institute (CRI), Bangkok, Thailand
Meeting dates: November 10-11, 2009

Day 1: November 10, 2009

9.00- 9.20 AM: Opening ceremony (by Dr. Hur and Dr. Saksit) + a group photo
9.20-9.30 AM: Introduction of APN project members
9.30- 10.00 AM: Introduction of APN project
10.00-10.15 AM: Presentation results of 1st review paper from Cambodia
10.15-10.30 AM: Presentation results of 1st review paper from Indonesia
10.30-10.50 AM: Discussion
10.50- 11.05 AM: Coffee break
11.05-11.20 AM: Presentation results of 1st review paper from Thailand
11.20-11.35 AM: Presentation results of 1st review paper from Vietnam
11.35-12.00 PM: Discussion
12.00 – 1.15 PM: Lunch
1.15-1.30 PM: Microbial sampling
1.30 – 3.10 PM: Cambodia: Presentation on river sampling & analysis (10 mins)
Indonesia: Presentation on river sampling & analysis (10 mins)
Discussion (30 mins)
Thailand: Presentation on river sampling & analysis (10 mins)
Vietnam: Presentation on river sampling & analysis (10 mins)
Discussion (30 mins)
3.10 – 3.30 PM: Coffee break
3.30 – 5.00 PM: Discussion on a comparative study (what are conclusions?)
5.00 – 6.30 PM: Discussion on 2nd data collection and database building (what are conclusions?)
7.00- 9.00 PM: Dinner

Day 2: November 11, 2009

9.00 – 10.30 AM: Discussion on
- 1st year timeline activities
- LAG (learning alliance group) establishment in each studied city
- Capacity building

10.30 – 10.45 AM: Coffee break
10.45 – 12.00 AM: Discussion on
- External funding
- Policy discussion and Next steps
- Summarizing 2 day meeting
- Closing remarks

12.00-2.00 PM: Lunch

"2nd APN Workshop on Strategic Policies for Sustainable Urban Water Quality Management in South East Asian Countries"

Date: 27 -28 July, 2010
Host organization: HCMC University of Technology, Vietnam
Location: HCMC University of Technology

Programme

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27 July, 2010:

8h30 – 9h00: Welcome/Registration

Session1: Sharing experiences of urban water quality management in each studied city

Chair: Dr. Ha
9h00 – 9h10: Opening Speech (Dr. Tien/Dr. Dan, HCMUT; Prof. Hur, GIST)
8h10 – 9h30: Presentation of Policy Makers from Cambodia (Dr. Tep)
9h30 – 9h50: Presentation of Policy Makers from Indonesia (Dr. Setiawan)
9h50 – 10h10: Presentation of Policy Makers from Thailand (Mr. Kasame)
10h10 – 10h30: Presentation of Policy Makers from Vietnam (Dr. Nga)
10h30 – 10h50: Coffee break

Session2: Policy analysis on urban water quality management

Chair: Dr. Ken
10h50 – 11h10: Presentation of APN members from Cambodia (2nd review paper: Mr. Vibol)
11h10 – 11h30: Presentation of APN members from Indonesia (2nd review paper: Ms. Maria)
11h30 – 11h50: Presentation of APN members from Thailand (2nd review paper: Dr. Soydao)
11h50 – 12h10: Presentation of APN members from Vietnam (2nd review paper: Dr. Ha)
12h10 – 13h30: Lunch at the campus

Session 3: Development of a strategic plan for sustainable urban water quality management in Southeast Asia (a group discussion)

Chairs: Prof. Thanh, Dr. Suthi, Dr. Setiawan and the Secertary – Dr. Ken
13h30 – 13h35: Introduction of outline discussion (Dr. Ha)
13h35 – 13h50: Presentation of database and 2nd data collection (Dr. Suthi)
13h50 – 14h30: Discussion on data sharing and 2nd data collection
14h30 – 15h15: Discussion on regional action plan for sustainable urban water quality management in SEA

- Supportying tools for decision making process (SWAT, database)
- Supporting tools for water quality risk assessment (monitoring network, Water Quality Index, Sustainability Index)
- Integration tools (for decision making process & water quality risk assessment) for establishing sustainable urban water quality management
- Analysis of possible integrated existing policies
- Capacity building for implementation of developed supporting tools
- What scientists can do for policy makers to improve urban water quality management?

15h15 – 15h30: Coffee break
15h30 – 16h30: Discussion on future plan to achieve sustainable urban water quality management
16h30 – 16h50: Wrap up section (Dr. Ken)
16h50 – 17h00: Closing speech (Prof. Thanh)
18h30 – 20:00: Dinner

28 July, 2010:

Session 4: Reporting results of 1st sampling

Chair: Dr. Suthi and Dr. Ken
9h00 – 9h20: Presentation of APN members from Cambodia (Results of 1st sampling)

9h20 – 9h40: Presentation of APN members from Indonesia (Results of 1st sampling)
9h40 – 10h10: Presentation of APN members from Thailand (Results of 1st sampling)
10h10 – 10h30: Presentation of APN members from Vietnam (Results of 1st sampling)
10h30 – 11h00: Presentation of APN members from Korea (Results of 1st sampling: Dr. Ken and Dr. Suthi)
11h00 – 11h15: Coffee break

Session 5: River basin management
Chair: Dr. Ken
11h15 – 11h45: Application of SWAT model on river basin management (Dr. Loi)
11h45 – 12h05: Comprehensive water quality index for 4 studied SEA countries (Ms. Phuong)
12h05 – 12h30: Discussion, Comments and closing the workshop (Dr. Suthi)
12h30 – 14h00: Farewell lunch at Ngoc Lan restaurant
14h00 – 17h00: Open meeting among APN scientific members (Prof. Thanh, Dr. Ha, Dr. Soydao, Ms. Maria, Mr. Vibol, Dr. Ken, Dr. Suthi)

- ☐ Biological sampling & analysis
- ☐ Chemical sampling (+heavy metals) & analysis
- ☐ Collection of 2nd data for SWAT
- ☐ Making new timeline activities (2nd year)
- ☐ Developing a strategic plan & implementation
- ☐ How to keep the set deadlines intact ???
- ☐ Database development (its contents)
- ☐ Collection of 2nd data for database
- ☐ Title&Contents of 3rd APN meeting in China
- ☐ Making a carbon copy of your sent e-mails to pchanpiwat@gist.ac.kr

GIST & APN Joint Meeting Program on Sustainable Urban Water Quality Management in South East Asian Countries

Dates: November 15-16, 2010
Venue: National Engineering Center AVR Room A, University of the Philippines in Diliman, Quezon City 1101
Contact: Maria Lourdes P. Dalida, PhD (632-929-6640, Or (632) 9818500 ext 3114)

Day 1: November 15, 2010 (Monday)
Chair: Dr. Analiza P. Rollon, Dr. Ken
9.00-9.15: - Opening ceremony by delegates from UP, APN and IERC-GIST
- A group photo
9.15-9.30: A brief introduction of APN project (Suthipong Sthiannopkao, a project leader)

Session I: Application of SWOT to analyze urban water quality management policies
Chair: Dr. Analiza P. Rollon, Dr. Ken
9.30-9.50: Presentation by a policy maker from Cambodia
9.50-10.10: Presentation by a policy maker from Indonesia
10.10-10.30: Presentation by a policy maker from Thailand
10.30-10.50: Presentation by a policy maker from Vietnam
10.50-11.05: Coffee break (15 mins)

Session II: Presentations by participants from the Philippines
Chair: Dr. Analiza P. Rollon, Dr. Ken
11.05-11.35 **"State of the Implementation of the Clean Water Act of the Philippines" Ms. Leza Acorda-Cuevas** Supervising Environmental Management Specialist Environmental Management Bureau (EMB) Dept. of Environment and Natural Resources- Philippinnes
11.35-12:05**:"Impacts of Climate Change on the Urban Water Resources" Prof .Dr. Carlos Primo C. David Professor** National Institute of Geological Sciences University of the Philippines-Diliman

12.05-13.30: Lunch

Session III: Seasonal variation of river water quality in South East Asian cities
Chair: Dr. Setiawan, Dr. Nga
13.30-13.50: Presentation by a scientist from Cambodia
13.50-14.10: Presentation by a scientist from Indonesia
14.10-14.30: Presentation by a scientist from Thailand
14.30-14.50: Presentation by a scientist from Vietnam
14.50-15.10: Coffee break (20 mins)

Session IV: Special presentations by Professors at SESE-GIST
Chair: Dr. Suthi
15.10-15.35: Special presentation 1
15.35-16.00: Special presentation 2

Session V: Open discussion of today presentations
Chair: Dr. Suthi, Dr. Ken, Dr. Rizalinda L. De Leon
16.00-17.00: Open discussion
18.00-20.00: Dinner (to be held at the Executive House, UP-Diliman)

Day 2: November 16, 2010 (Tuesday)

9.00-12.00: Meeting of APN members (Scientists & Policy Makers)

- ☐ Development of WQI for SEA countries
- ☐ 2nd data collection (for statistical & SWAT analyses)
- ☐ Future activities

-Database building

-Next workshops (on SWAT)

-Publications

-Modeling (SWAT)

-Recruiting new members (HEPA, Manila)

Sampling for total heavy metals (250 ml sample) & isolates

- Raising local funds
- Others

12.00- 13.30: Lunch

4th APN Meeting Program

"Drafting a Strategic Plan for Sustainable Urban Water Quality Management in Southeast Asia"

Dates: May 30-31, 2011 (Two full day meeting)
Venue: Bali, Indonesia
Contact: suthisuthi@gmail.com, suthi@mail.ncku.edu.tw

Day 1: May 30, 2011

Chair: Dr. Kenneth Widmer, Ms. Maria Angela Novi Prasetiai
8.45-9.00: Registration
9.00-9.20: Opening ceremony (Drs. Suthipong Sthiannopkao, Setiawan)
9.20-9.50: A comparative study of Southeast Asia urban water quality (Cambodia, Indonesia, Thailand and Vietnam): Aspects of trace metals (Dr. Suthipong Sthiannopkao, NCKU, Taiwan)
9.50-10.10: A comparative study of Southeast Asia urban water quality (Cambodia, Indonesia, Thailand and Vietnam): Aspects of pathogens (Dr. Kenneth Widmer, GIST, Korea)
10.10-10.30: Break
Chair: Drs. Kenneth Widmer, Ha
10.30-11.00: A comparative study of Southeast Asia urban water quality (Cambodia, Indonesia, Thailand and Vietnam): Aspects of general water quality characteristics (Mr. San Vibol, RUPP, Cambodia)
11.00-11.30: Development of Water Quality Index for Southeast Asian Rivers (Dr. Soydoa Vinitnantharat, KMUTT, Thailand)
11.30-12.00: A study of Saigon River Sediments: Aspects of trace metals (Dr. Nguyen Thi Van Ha, HCMUT, Vietnam)
12.00-13.30: Lunch
Chair: Drs. Suthipong Sthiannopkao, Soydoa Vinitnantharat
13.30-14.30: Best Management Practices for Southeast Asian Rivers (an invited speaker, USA)
14.30-15.00: Application of SWOT for analyzing urban water quality management policy in Southeast Asia (Cambodia, Indonesia, Thailand and Vietnam) (Dr. Setiawan Wangsaatmaja, West Java-EPA, Indonesia)
15.00-15.20: Break
Chair: Drs. Suthipong Sthiannopkao, Soydoa Vinitnantharat
15.20-16.00: APN database (Dr. Kenneth Widmer, GIST, Korea)
16.00-17.00: Introduction of SWAT (an invited speaker, USA)
18.00-19.30: Dinner
Day 2: May 31, 2011
Chair: Drs. Kenneth Widmer, Suthipong Sthiannopkao
9.00-9.20: Strategies for implementation of APN's scientific results for Bangkok water quality management (Mr. Kasame Thepnoo, BMA, Thailand)
9.20-9.40: Strategies for implementation of APN's scientific results for Bandung water quality management (Ms. Maria Angela Novi Prasetiai, West Java-EPA, Indonesia)
9.40-10.30: Drafting of a strategic plan I (all participants)
10.30-10.50: Break
10.50-12.00: Drafting of a strategic plan II (all participants)
12.00-13.30: Lunch
13.30-14.00: Propose of a draft for strategic plan (Drs. Kenneth Widmer, Suthipong Sthiannopkao)
14.00-14.40: Discuss on APN database
14.40-15.10: Discuss on 1st year publications (papers obtained from Drs. Setiawan, Soydoa, Ha, Vibol, Ken, Suthi)
15.10-15.40: Report on progress of securing local funding sources (Mr. Kasame, Dr. Setiawan, Dr. Ha)
15.40-16.30: Final meeting in Korea to present our strategic plan to policy makers

5th APN Meeting Program

"Sustainable Urban Water Quality Management in Southeast Asia:
Implementation of Research Development Tools"
Date: Nov. 1, 2011
Venue: Depak C. Jain Meeting room (1st Fl.), Sasa international House, Chulalongkorn University, Bangkok
Contact: Dr. Suthipong Sthiannopako (suthi@mail.ncku.edu.tw)
8.40-9.00: Registration
Session 0: Opening ceremony
(Chair: Dr. Chantra Tongcumpou)
9.00-9.30: - Opening ceremony (by BMA representative, Drs. Linda Stevenson, Jariya Boonjawat (APN), and Dr. Suthipong Sthiannopkao (APN's project leader))
- Introduction of participants
- A group photograph
Session 1: APN project overview
(Chair: Dr. Chantra Tongcumpou)
9.30-9.45: Overview of APN project (Dr. Suthipong Sthiannopkao)
Session 2: Water quality risk assessment in Southeast Asian rivers
(Chair: Dr. Suthipong Sthiannopkao)
9.45-10.15: Risk assessment – A case study of microbiological contamination in Southeast Asian rivers (Dr. Kenneth Widmer)
10.15-10.45: Risk assessment – A case study of heavy metals contamination in Southeast Asian rivers (Dr. Suthipong Sthiannopkao)
10.45-11.00: Break
Session 3: Application of research developed tools for urban water quality management I
(Chair: Dr. Setiawan Wangsaatmaja)
11.00-11.30: Application of SWAT model to predict water quality in the Chao Phraya river basin (Dr. Kyung Hwa Cho)
11.30-12.00: Development and applications for a regional water quality index (Dr. Nguyen Thi Van Ha)
12.00-13.30: Lunch
Session 4: Application of research developed tools for urban water quality management II
(Chair: Prof. Nguyen Cong Thanh)
13.30-14.00: Development of water sustainable index (Dr. Soydoa Vinitnantharat)
14.00-14.30: SWOT applications for urban water policies (Dr. Setiawan Wangsaatmaja)
14.30-14.50: The future of SEAWED (Southeast Asian Water Environment Database) – Where we intend to expand. What the future plans are for the database. How public administrators can utilize this now and for future issues regarding urban water quality (Dr. Kenneth Widmer).
14.50-15.15: Break
Session 5: Discussion on SEAWED and Implementation of Research tools
(Chairs: Dr. Kenneth Widmer, Dr. Suthipong Sthainnopkao)
15.15-16.00: Gathering comments/suggestions from invited participants on applying and improving SEAWED & other research tools for urban water quality management (Dr. Kenneth Widmer, Dr. Suthipong Sthainnopkao)
Date: Nov. 2, 2011
Session 6: APN members' meeting
9.30-12.30: Discussion among APN members
- Final APN report
- 2012 research application
- Research fund sources
12.30-14.00: Lunch

Agenda/Programme (including title, date and venue)
Participants list (comprising contact details of each participant, including organisation, address, phone number, fax number, and email address)

Funding sources outside the APN

International Environmental Research Center at Gwangju Institute of Science and Technology, Korea, has financially supported eight persons working on this APN project to attend its internship program for a four month period.

Glossary of Terms

Include list of acronyms and abbreviations

BOD = Biological Oxygen Demand
CCC = Criterion Continuous Concentration
CCU = Cumulative Criterion Unit
COD = Chemical Oxygen Demand
DO = Dissolved Oxygen
FCB = Fecal Coliform Bacteria
GIST = Gwangju Institute of Science and Technology
HCMC = Ho Chi Minh City
SEA= Southeast Asia
SWAT= Soil and Water Assessment Tool
SWOT= Strengths, Weaknesses, Opportunities, and Threats
TCB = Total Coliform Bacteria
TDS = Total dissolved solids
TN = Total Nitrogen
TP = Total phosphorus
TSS = Total suspended solids
WQI= Water Quality Index
WSI= Water Sustainability Index