Asia-Pacific Network for Global Change Research

Regional Collaborative Research on Climate Change Impacts on Surface Water Quality in Eastern Monsoon Asia: Towards Sound Management of Climate Risks

Final report for APN project: ARCP2008-04CMY-Park

The following collaborators worked on this project:

Ji-Hyung Park, Kangwon National University, Korea, jihyunpark@kangwon.ac.kr (project leader)
Kyoung-Woong Kim, GIST, Korea, kwkim@gist.ac.kr
Edu Inam, GIST, Korea, edu@gist.ac.kr
Suthipong Sthiannopkao, GIST, Korea, suthi@gist.ac.kr
M. Harun Abdullah, University of Malaysia Sabah, Malaysia, harunabd@ums.edu.my
Dwi Agustyani, Indonesian Institute of Sciences, Indonesia, titinagustin@yahoo.com
Lei Duan, Tsinghua University, China, lduan@tsinghua.edu.cn
My Hoa Nguyen, Cantho University, Vietnam, nmhoa@ctu.edu.vn
Vibol Sao, Royal University of Agriculture, Cambodia, saovibol@yahoo.com
Sianouvong Savathvong, Souphanouvong Universityk, Lao PDR, sianouv@yahoo.com
J. Keith Syers, Mae Fah Luang University, Thailand, keith@mfu.ac.th
Wanpen Wirojanagud, Kohn Kaen University, Thailand, wanpen@kku.ac.th

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Final Report submitted to APN

Overview of project work and outcomes

Non-technical summary

Freshwater resources in East Asia might be very vulnerable to climate change due to large climatic variability associated with the monsoon system and rising water demand. To obtain scientific information essential for the assessment of 'climate risks' to surface water quality, a collaborative research involving 12 scientists of eight East Asian countries was conducted for two years using combined approaches of academic meetings, field monitoring and climate risk assessment. The scoping workshop in Chuncheon, Korea, 2007 aimed to provide an overview of climate change impacts on surface water quality in major sub-regions of East Asia. Climate effects on water quality were further examined by field monitoring including a cross-site comparison of seasonality and spatial differences in water quality across the region and intensive monitoring at three selected sites. At the synthesis workshop in Kota Kinabalu, Malaysia, 2009, water quality data collected from field monitoring and local sources were evaluated in light of assessment and management of climate risks. The overall results suggest that climate change, and changes in monsoon rainfall regimes in particular, can affect surface water quality across East Asia. The magnitude of environmental and socio-economic impacts would depend on the vulnerability of impacted areas and water quality parameters considered. Pro-active management of climate risks to water quality and expected environmental and socio-economic losses requires further investment of interdisciplinary research efforts in understanding and predicting site-specific environmental impacts of climate change and variability.

Objectives

The main objectives of the project were:

1. Enhanced understanding of responses of water flow and its chemical loads to climate variability including extreme hydrologic events such as droughts, heavy rainfalls, and floods
2. Translation of scientific data into practical information essential for the development of an integrated system for the assessment and management of climate risks associated with surface water quality

Amount received and number years supported

The Grant awarded to this project was:

US$ 42,000 for Year1, 2007-2008; US$ 38,000 for Year 2, 2008-2009:

Activity undertaken

The first ‘scoping’ workshop was held at Kangwon National University, Korea, October 7-9, 2007. The primary objective of the first workshop was to review key problems and topics concerning climate impacts on water quality, with three specific aims: identifying emerging trends, planning long-term monitoring, and linking science with climate risk management. The primary objective of the ‘synthesis’ workshop in Kota Kinabalu was to evaluate data collected from field monitoring and local sources to assess ‘climate risks’ associated with changes in surface water quality as a function of changes in hydroclimates and land use. For a cross-site comparison of seasonal differences in water quality, biannual water sampling was conducted in altogether eight countries between July 2007 and April 2008, building on a pilot study conducted in four countries in 2006. In the second year, intensive monitoring at the hourly to daily time scale was conducted at three selected mixed-land use watersheds, including Punch Bowl Watershed in Yanggu, Korea, Khan River Watershed in Luang Prabang, Lao PDR and Kiulu River Watershed in Kota Kinabalu, Malaysia. The data collected from field monitoring, along with long-term climate and water quality data from local sources, were evaluated in the context of translating scientific data into practical information for the assessment and management of climate risks.

Results

Comprehensive literature reviews done as part of Project Module 1 have identified complex relationships between climate and surface water quality in East Asia. Increasing variability and extremes in precipitation have been observed across many parts of East Asia. In northern latitudes winter snowpack dynamics and soil freeze/thaw cycles will play a pivotal role in the release of acids and nutrients from steep hillslopes. In mid latitudes including the Korean Peninsula increasing amount and intensity of summer monsoon rainfalls, in combination with land use change and steep topography have been predicted to lead to water quality deterioration by increased transport of sediments and nutrients. In southern China, lower precipitation with large year-to-year variations appears to have had a substantial influence on year-to-year variations in acidity and nutrient fluxes in forest soils and headwater streams under increasing levels of acid deposition. Although patterns of recent climate change in Southeast Asia have been more complex and subtle, our review identified parameter-specific water quality responses to recent or future climate changes, including decreases in DO saturation during hot and dry periods and a very strong control of hydroclimates on SS. Field monitoring results showed that increased rainfalls during wet season can increase terrestrial inputs of suspended sediments and dissolved organic matter from various non-point sources, while increased streamflow can lead to in-stream dilution of some chemicals having limited inputs via surface runoff. The results from the intensive monitoring conducted at two selected watersheds showed that flashy responses of watershed export of sediments and associated contaminants (e.g., toxic metals) to intense and extreme rainfalls could pose a threat to surface water quality in vulnerable areas such as steep mountainous watersheds, with climate impacts often amplified by land use change. Overall results suggest that climate change can affect surface water quality in East Asia, while the magnitudes of environmental and socio-economic impacts would depend on the vulnerability of impacted areas and water quality parameters considered. Efficient systems of climate risk management can build on this scientific assessment and prediction of site- and parameter-specific risks and associated ecological and socio-economic losses.

Relevance to APN's Science Agenda and objectives

The project addressed three APN science issues: climate (climate change impacts on surface water quality); ecosystems (hydro-biogeochemical processes in terrestrial and aquatic ecosystems); and water resources management for sustainable development. The topics addressed and approaches employed are crosscutting. Project results will provide scientific baseline information for the management of risks associated with climate variability and change that pose particular threats to freshwater resources in countries under strong influence of monsoon systems and thus vulnerable to changing climate.

Self evaluation

The primary objective of the project was to build a regional collaborative research network linking individual research efforts focused on climate change impacts in water sector at the local scale. Through two workshops and on-site collaborations the project has contributed to connecting otherwise scattered research efforts into a researcher network covering most of East Asian regions. While our review and field monitoring have shed light on future research directions, some of research questions, particularly those of Project Module 3, were inadequately addressed. Since climate risk management consists not only of scientific assessment of identified climate risks but also of evaluation of expected ecological and socio-economic losses, developing full-fledged risk management systems require more interdisciplinary approaches.

Potential for further work

To maintain the collaboration network on a long-term basis would require further research activities, including follow-up research projects at national or international scales, researcher exchange and capacity building of next-generation scientists. Information dissemination will facilitate increased access and utilization of existing long-term data such as data bases maintained by MRC. On the other hand more rigorous efforts should be paid to initiate or expand national water quality monitoring programs benchmarking model programs in European and North American countries. Future study of climate change impacts on water quality needs to invest more efforts to site-specific water quality issues and the translation of obtained scientific data into practical information for sound management of climate risks to surface water quality.

Publications

Park JH. Inam E, Kim KW (eds.). 2007. Proceedings of The First International Workshop on Climate Change Impacts on Surface Water Quality in East Asian Watersheds held October 8-9, 2007, Chuncheon, Korea. International Environmental Research Center, Gwnagju, Korea

Park JH, Inam E, Kim KW (eds.). 2009. Proceedings of the Second International Workshop on Climate Change Impacts on Surface Water Quality in East Asian Watersheds, February 18-20, 2009, Universiti Malaysia Sabah, International Environmental Research Center, Gwangju, Korea.

Park JH, Duan L, Kim B, Mitchell MJ, Shibata H. Potential effects of climate variability and extremity on watershed biogeochemical processes and water quality – a synthesis for Northeast Asia. Environment International (in revision).

Park JH and all APN project members. Monsoon effects on temporal variations in surface water quality in East Asian watersheds (in preparation)

Syers JK, Bach NL, Sthiannopkao S, Yolthantham T. Impacts of climate change on water quality in a tropical watershed: a case study from the Kok River, Chiang Rai, Thailand. Journal of Environmental Quality (in review)

8 presentations at academic conferences

Acknowledgments

Funding for all projects activities was provided by APN through START, with additional funding for the first and second workshops provided by Kangwon National University and Universiti Malaysia Sabah, respectively. Second-year intensive monitoring at the Korean site was partially supported by a grant from Korea Research Foundation funded by the Korean Government (KRF-2007-313-F0033).

Technical Report

Preface

This APN-funded project was conducted as a collaborative research coordinated by International Environmental Research Center (IERC), Gwangju Institute of Science & Technology, Korea. Although climate change is emerging as a new challenge for sound management of water resources in East Asia, there have been rare efforts to link researchers interested in this issue. Based on research networks in monitoring of East Asian environments, IERC took initiative to conduct the first regional scale research focusing on climate change impacts on surface water quality. Through a combination of three different approaches including two workshops, field monitoring and climate risk assessment, the project aimed to provide an overview of potential effects of climate change and variability on surface water quality in major regions of East Asia, with practical recommendations for developing a scientific climate risk management system as an important project outcome.

The success of the project was possible through whole-heartedly commitments of 12 scientists from eight East Asian countries. Dr. Edu Inam at IERC coordinated administrative and scientific works for both the preparation of two workshops and field monitoring at eight countries. Institute of Forest Science, Kangwon National University and Universiti Malaysia Sabah provided workshop venues and financial support as the co-organizer of the first and second workshop, respectively. It is also acknowledged that numerous research staff and students of the project member labs helped with sample collection and analyses for the pilot study in 2006 and two-year main monitoring activities. The last, but not least thanks go to APN staff for their superb assistance in all stage of project implementation. Dr. Linda Stevenson showed an illustrative example of professional support from APN staff by her participation and contribution at the synthesis workshop.

Ji-Hyung Park,
Project leader and
Professor in environmental biogeochemistry,
Kangwon National University,
Korea

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1.0 Introduction

Climate change, together with population growth and pollution, represents an emerging challenge for sound management of water resources (IPCC, 2001; WWAP, 2006). Intensifying hydrologic cycle as a consequence of climate change has been predicted to have significant impacts on streamflow and hence the availability of global water resources (Vörösmarty et al., 2000; Milly et al., 2005). Compared to the substantial attention paid to climate change effects on hydrologic cycle, little is yet known about climate risks associated with changes in water quality, while climate change, particularly extreme hydrologic events such as floods and droughts, has been suggested to have significant impacts on water quality around the world (IPCC, 2001; Senhorst and Zwolsman, 2005). East Asia including both Northeast and Southeast regions represents a hot spot of climate vulnerability in freshwater resources, due to extreme hydrologic variability associated with monsoon systems and increasing water demand from the extraordinary pace of economic development. Increasing extreme hydrologic events have been observed in the recent decades and projected for the coming decades across the region (Manton et al., 2001; IPCC, 2001). This intensifying hydrologic cycle has been linked to changes in streamflow and the availability of freshwater resources (Milly et al., 2005; SEA START RC, 2005). However, there has been rare effort to link changes in hydrologic cycles with the quality of surface water resources except some pioneering activities of regional research centers (e.g., MRC and SEA START RC).

Climate change impacts on water quality are determined not only by changes in water's biological, chemical, and physical characteristics but also by changes in hydrological and biogeochemical processes along watershed flowpaths that regulate the production, release, and transport of natural materials and contaminants (Jacobs et al., 2000). A combination of changes in temperature and total precipitation and water flow variability associated with extreme hydrologic events leads to changes in land surface processes (e.g., stormflow effects on contaminant mobilization) as well as water quality deterioration in water body (e.g., adverse effects of temperature and droughts on DO and aquatic organisms (Senhorst and Zwolsman, 2005). Some recent studies exemplified by SEA START RC's projects have advanced our understanding of changes in the flow of water and its chemical loads in response to changing land use and climate over SE Asian river basins (Richey et al., 2000; SEA START RC, 2005). For example, the developing model of regional water and material transport incorporates a water chemistry submodel, allowing quantification of climate change impacts on riverine transport of nutrients and other contaminants (Richey et al., 2000). The lack of quality monitoring data has been a major obstacle to the successful model application in evaluating long-term or short-term, flash responses of watershed material transport to different modes of climate variability and change. Another major limitation of current monitoring programs is their focus on conventional water quality parameters (e.g., MRC monitoring data), neglecting emerging water pollution issues such as toxic metals and organic pollutants (Isobe et al., 2002; Cenci & Martin, 2004).

Pro-active management of climate risks requires the integration of risk information into institutional and policy contexts as well as identifying and timely informing specific climate risks (IRI, 2005). Although most East Asian countries have relatively well-developed risk managements systems to provide relief during natural disasters generated by monsoon systems, ENSO, and typhoons, these ‘re-active’ relief programs usually target at hydrologic hazards as exemplified by flood prevention efforts in Mekong River Basin (MRC, 2003). Water pollution with pathogens and toxicants has been documented as a major water-related hazard following extreme hydrologic events including floods (Stachel et al., 2004; Presley et al., 2006). It has yet rarely been studied of how the risks from climate-induced changes to water quality can be quantified accurately using risk assessment models and further incorporated into risk management strategies.

Despite pressing needs for sound management of water resources, there are huge gaps in scientific understanding of natural and socio-economic controls on the availability and quality of fresh water resources. The primary objective of the proposed project is to launch a regional collaborative research network focusing on climate risks imposed on surface water quality in response to increasing extreme events. Specific goals include (1) enhanced understanding of responses of water flow and its chemical loads to extreme hydrologic events such as droughts, heavy rainfalls, and floods; and (2) translation of scientific information into practical tools for sound risk management, including risk classification and predictive modeling.

2.0 Methodology

2.1. Project Module 1 – the first and second workshops

The first ‘scoping’ workshop was held at Kangwon National University in Chuncheon, Korea between October 7-9, 2007. The primary objective of the first workshop was to review key problems and topics related to climate impacts on water quality, with three specific aims: identifying emerging trends, planning long-term monitoring, and linking science with climate risk management. Eleven project members, together with nine invited speakers, provided overviews on key problems and topics regarding climate change and surface water quality in East Asia and discussed practical problems encountered while implementing planed project activities. Key research topics were prioritized to plan follow-up activities and future full-fledged research projects.

The primary objective of the 'synthesis' workshop lied in evaluating data collected from our field monitoring and local sources to assess 'climate risks' associated with changes in surface water quality as a function of changes in hydroclimates. The workshop also aimed to produce future research plans for developing science linkages to climate risk management as well as for building up a larger-scale regional monitoring network.

The outcomes of the workshops include the workshop proceedings and two ad-hoc review groups summarizing major findings and discussions of the workshop. The proceedings can be downloaded from the project homepage (http://apn.frp92.org). The first review group, consisting of Drs. J.H. Park, L. Duan, B. Kim, M.J. Mitchell, and H. Shibata, focused on providing an overview on climate change impacts on biogeochemical processes and surface water quality in Northeast Asia. The manuscript is now in final revision for publication in the journal 'Environment International'. An excerpt from the review is presented in the first section of the Results and Discussion (3.1). Other major findings of the two workshops are summarized in the section 3.2. Overview of climate change impacts on surface water quality in Southeast Asia and 3.5. Climate risk assessment.

2.2. Project Module 2 – field monitoring

The pilot study in 2006 and the first-year cross-site comparison in 2007-2008

Biannual water quality monitoring was conducted at altogether 11 watersheds of 8 East Asian countries in two different sampling campaigns (Figure 2.1; Table 2.1). The fist sampling campaign in 2006 was conducted as a pilot study at five watersheds of four East Asian countries. A more extensive sampling campaign was conducted at nine watersheds of eight countries from July 2007 through May 2008.

Fig. 2.1. Sampling locations in altogether 11 watersheds monitored from 2006 to 2008.

Table 1. Sampling locations and sampling time for the pilot study in 2006 and 2007-2008 campaigns.

Site name	Country	Sampled rivers & tributaries	No. of sampling sites (06/07-08)	Sampling time	(dry/wet)
				06 campaign	07-08 campaign
Shanxi	China	Penhe	9		Mar 08/Jul 07
Chuncheon	Korea	Soyang	9		Aug 07/ May 08
Gwangju	Korea	Hwangryong	6	Mar 06/Aug 06	
Chiang Rai	Thailand	Kok & Mekong	15	Mar 06/Aug 06	
Ubon Ratchatani	Thailand	Mun & Mekong	14/9	Mar 06/Aug 06	Mar 08/Jul 07
Luang Prabang	Lao PDR	Khan & Mekong	5		Mar 08/Jul 07
Vientiane	Lao PDR	Ton & Mekong	9		Mar 08/Jul 07
Phnom Penh	Cambodia	Tonle Sap & Mekong	11/9	Mar 06/Aug 06	Mar 08/Jul 07
Cantho	Vietnam	Mekong	9		Mar 08/Jul 07
Kota Kinabalu	Malaysia	Kiulu	14/9	Jul 06/ Apr 06	Nov 07/May 08
Bogor	Indonesia	Ciliwung	9		Sep 07/Mar 08

In both campaigns water sampling was repeated two times, one during dry period and another during wet period, at the same location of 5-15 sites per each monitored watershed. The sites in Ubon Ratchatani, Phnom Penh, and Kota Kinabalu were sampled for both sampling campaigns, thus enabling comparison of year-to-year variations in seasonal differences in water quality. For comparison of seasonality in water quality, sampling time was carefully selected to represent a typical dry vs. wet period of each country. In six countries under direct or some influence of East Asian monsoon dry-season sampling was conduced between mid March and late April following at least one week of no precipitation, while wet-season sampling was done around the peak of summer monsoon. Since Malaysia and Indonesia do not have distinct summer monsoon period, different sampling timing was selected based on local weather conditions. For more details on sampling, refer to Inam and Park (2009) in this volume.

The second-year intensive monitoring

Intensive water sampling had been planned for three watersheds in Korea, Lao PDR, and Malaysia (Table 2.1). Here we report monitoring results from the Korean and Lao sites, because monitoring at the Malaysian site has not yet been completed due to the lack of storm events with expected intensity and duration over the targeted wet period between October and December 2008. Malaysian research group will conduct sampling whenever appropriate storm events occur in 2009.

Short-term intensive water sampling, combined with real-time water quality monitoring, was conducted at a mountainous, mixed-land use watershed in Korea between late June and late July 2008 (Fig. 2.2). At the ‘Punch Bowl Watershed’ in which agricultural expansion has drastically transformed the predominantly forested landscape over the last couple of decades, short-term responses of surface water quality to monsoon rainfalls with different degrees of intensity and duration were compared at a forest stream and a downstream agricultural site. The agricultural site is located at the lowermost reach of Mandae Stream, a tributary of Inbuk River, while the forest stream draining a small forested watershed located on an upper slope of the bowl-shaped basin is a headwater tributary to Mandae Stream. During four rainfall events from late June through july water samples were collected every two hour using two autosamplers (6712 Portable Sampler, ISCO, Lincoln, USA). Over the same sampling periods, real-time changes in pH, conductivity, and turbidity were monitored every minute with a multi-parameter water quality probe (6920 Water Quality Monitoring System, YSI, Fort Worth, USA).

Table 2.1. Study sites in Korea, Lao PDR, and Malaysia.

Study site	Location	Watershed characteristics	Soil erodibility	Water pollution
Punch Bowl Watershed	Yanggu, Korea	Steep mountain watershed with an increasing proportion of agricultural lands	High	Medium to high
Kahn/Mekong Watershed	Luang Prabang, Lao PDR	Steep mountain watershed with a large-scale deforestation	Very high	Medium
Kiulu River Watershed	Kota Kinabalu, Malaysia	Mountain watershed with a large forest cover	Low	Low

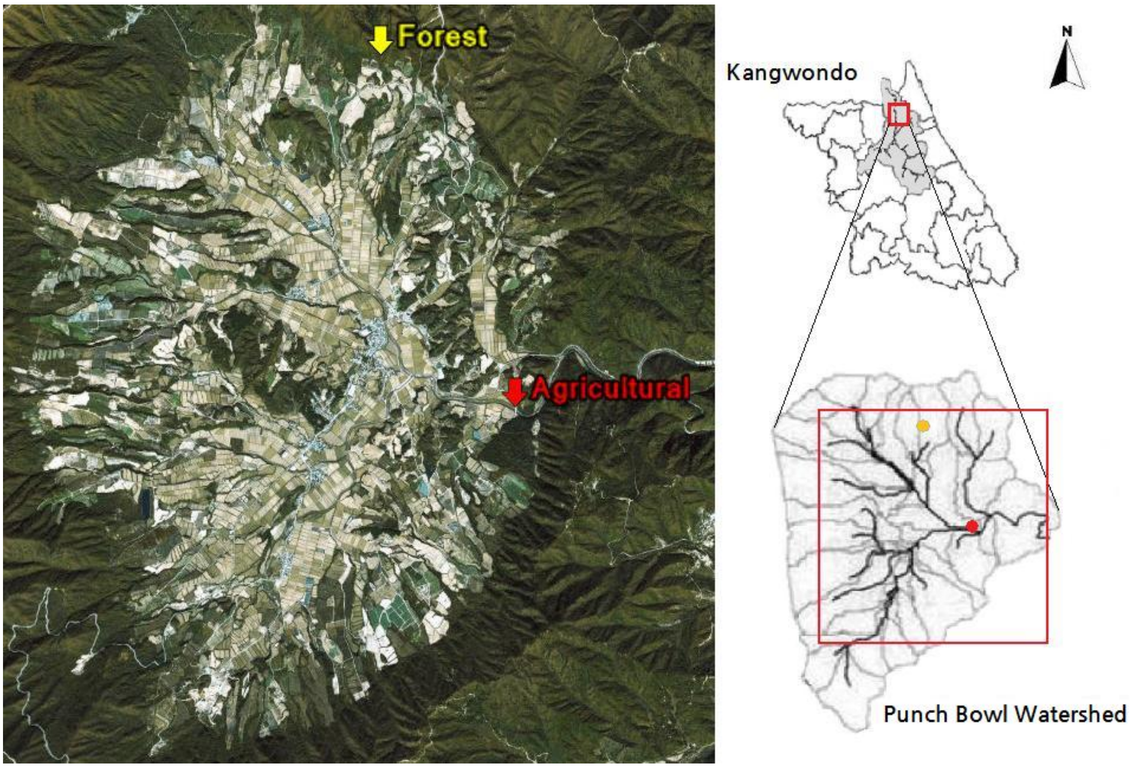


Fig. 2.2. Locations of intensive water quality sampling in Punch Bowl Watershed, Kangwondo, Korea

In Luang Prabang, Lao PDR, real-time water quality monitoring around the peak flow during an extreme flooding event in August, followed by a daily water quality monitoring over the two weeks in September, were conducted along the mainstem and tributary streams of Mekong and Khan River from early August through mid September, 2008 (Fig. 2.3). Real-time water quality monitoring was conducted with the YSI water quality probe on two separate boat trips along the mainstem of Khan and Mekong River one day before and two days after the flooding event, which has been the largest in Luang Prabang since 1966. Over the two weeks from September 2 to 13, daily water sampling was conducted at a downstream location of Khan River, an agricultural stream (Mout Stream), and a forest stream (Pa Stream).

Fig. 2.3. Sampling locations along the mainstem of Mekong and Khan River and at an agricultural (Mout Stream) and a forest stream (Pa Stream).

Immediately after water sampling, subsamples were filtered on-site using a syringe filter and added with concentrated nitric acid for future analysis of dissolved metals. The filterates, together with unfiltered samples, were frozen prior to the transport to the laboratory in Chuncheon, Korea. Water quality parameters analyzed at the laboratory include total suspended solid (TSS) as a measure of sediment loads, size fractionation of sediments, dissolved organic carbon (DOC), particulate organic carbon (POC), UV absorbance (UVA) at 254 nm, and dissolved and particulate metals. For the measurement of particulate metals in three different size fractions of suspended sediments, subsamples were filtered through three different polycarbonate filters with nominal pore size of 0.4 µm, 60 µm, and 2 mm, respectively.

Sediments collected on the polycarbonate filters were digested with concentrated nitric acid on a hot plate. Metal concentrations in both dissolved and particulate phases were measured using ICP-MS to determine storm-induced changes in the dominant form of metals in surface waters.

2.3. Project Module 3 – climate risk assessment and management

Long-term data analyses presented during the second workshops and two-year monitoring data were examined in light of climate risk identification and assessment and their incorporation into the conceptual framework for developing climate risk management system. Statistical analyses including correlation and regression analyses were conducted to find relationships between climatic and water quality parameters. Empirical relationships were established while analyzing long term data from local sources and data collected from the second-year intensive monitoring and examined for possible application to predictive modeling. These data analyses, along with literature review on climate risks, were further evaluated to suggest some recommendations for developing the framework for climate risk management system focusing on surface water quality.

3.0 Results & Discussion

3.1. Overview of climate change impacts on surface water quality in Northeast Asia – Results from the first workshop (revised manuscript in review for publication)

Climate effects on watershed biogeochemical processes and environmental implications

Recent reviews on climate change impacts on surface water quality have emphasized that climate change affects water quality through complex interactions with both terrestrial and aquatic processes (Murdoch et al. 2000; Senhorst and Zwolsman 2005; Kundzewicz et al. 2007; Campbell et al. 2008). Surface water quality can be defined as a function of the chemical, physical, and biological characteristics. However, climate change, either long-term average changes or short-term variability including extremes, influence water quality, not only by directly changing the characteristics of the water, but also by influencing land surface processes regulating the production, release, and transport of natural materials and anthropogenic contaminants (Fig. 3.1.1). Changes in temperature and precipitation, along with irregular extreme hydrologic events, lead to changes in land surface geomorphic (e.g., hillslope failures) or hydro-biogeochemical processes (e.g., stormflow effects on contaminant mobilization) as well as deterioration in water quality (e.g., adverse effects of temperature and droughts on dissolved oxygen and aquatic organisms).

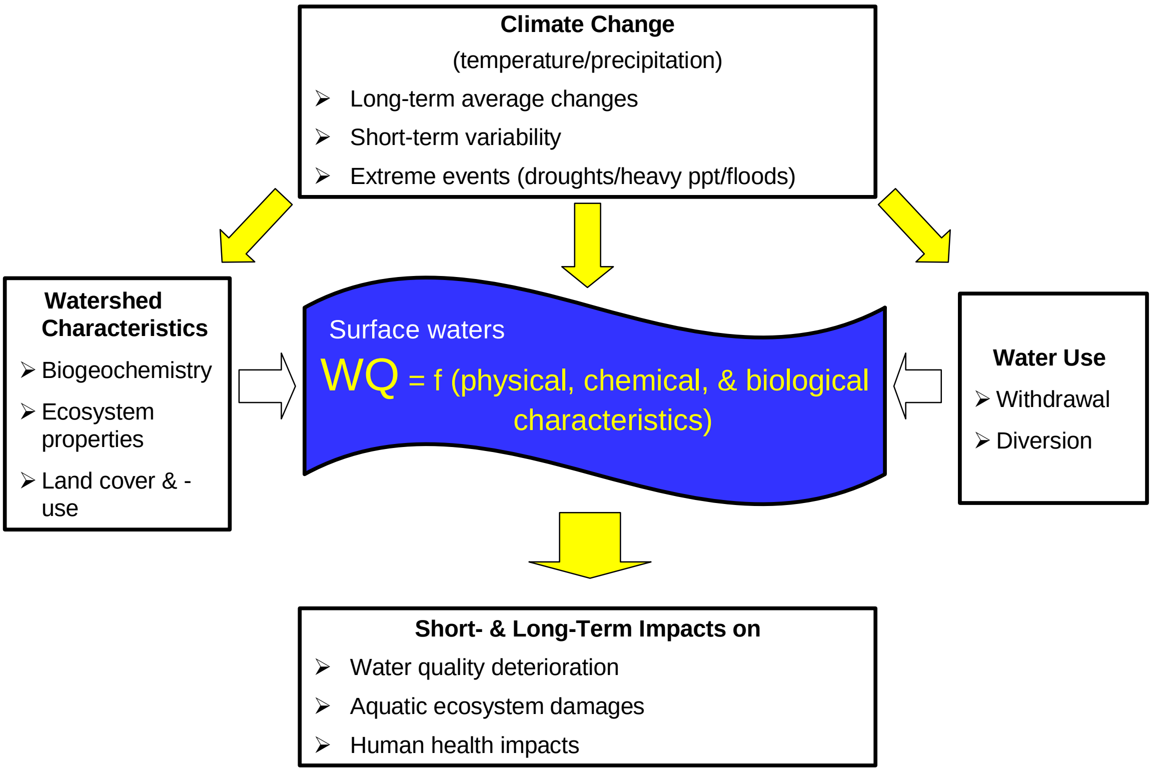


Fig. 3.1.1. Conceptual model of climate change impacts on watershed biogeochemical processes and surface water quality

Many hydroclimatic factors play important roles in land-water transport of chemicals affecting downstream water quality, including water and air temperature, precipitation amount and intensity, and droughts. Water temperature effects on water quality occur either directly from water temperature variations or indirectly through thermal pollution (e.g., water temperature increases due to cooling water discharges from the energy production facilities; Senhorst and Zwolsman 2005). Water temperature changes can directly influence temperature-dependent water quality parameters including dissolved oxygen, redox potentials, pH, lake stratification and mixing, and microbial activity (Kundzewicz et al. 2007).

Warming affects numerous land surface processes involved in chemical transport and water quality deterioration, as exemplified by warming-induced increases in soil N transformation leading to changes in streamwater nitrate concentrations (Murdoch et al. 1998) or hydrologic flushing of soil nitrate or DOC triggered by winter temperature fluctuations (Park et al. 2003 and 2005). Similarly, changing patterns of precipitation can exert influences on both land and water processes. Major precipitation-related water quality issues in three Northeast Asian countries (Japan, Korea, and China) are provided in the following case studies with particular focus on the effects of changing precipitation regimes that play a critical role on biogeochemical processes and water quality in the watersheds of this region.

Climate change and variability in Northeast Asia

As in other parts of Asia, unambiguous warming trends have been observed across Northeast Asia over recent decades, with more pronounced warming seasonally in winter and spatially in northern latitudes (Cruz et al. 2007). By contrast, precipitation trends show large inter-seasonal, inter-annual, and spatial variability across NE Asia (Cruz et al. 2007). For example, annual precipitation tends to have increased over the last century in South Korea (Chung et al. 2004), while declining or no trends in precipitation have been observed in Northeast China and Japan, respectively (Cruz et al. 2007). The frequency and intensity of extreme weather events, particularly heavy rainfalls during the summer monsoon, have increased in many parts of Northeast Asia, although spatial variation makes it difficult to draw general conclusions on the trends relevant across the entire region (Easterling et al. 2000; Manton et al. 2001; Jung et al. 2002; Cruz et al. 2007). As with the increasing frequency and intensity of tropical storms originating in the Pacific (Wu et al. 2005; Cruz et al. 2007), the increasing frequency of extreme precipitation events has been ascribed to global warming (Jung et al. 2002).

Among the observed climate trends in Northeast Asia, changing rainfall patterns during summer monsoon and changes in winter climate regimes (the latter especially in northern latitudes) have very important implications for watershed biogeochemical processes and hence surface water quality. For this region the majority of annual runoff is concentrated around summer monsoon period in the south and spring snowmelt in the north (Kim et al. 2000; Shibata et al. 2002). In Korea, changing rainfall patterns during summer monsoons (called “Changma”) have been observed over the recent decades, with a shortened duration of Changma and increased frequency of heavy rainfalls particularly in August (Chung et al. 2004). Long-term changes in East Asian monsoons have been linked to changes in Northern Hemisphere summer insolation (incoming solar radiation) on orbital time scales ranging from thousands of years to tens of millennia (Wang et al. 2008). However, the sensitivity of monsoons to climate changes might result in a stronger monsoon with large increase in monsoon precipitation (Overpeck and Cole 2008). Although little is yet known about the response of winter monsoon to climatic warming, a recent climate simulation over the southern half of the Korean Peninsula predicts declines in winter snow depth in response to the increase of minimum temperature and large increases in winter precipitation (Im et al. 2008).

Potential changes in winter monsoon in northern latitudes and implications for watershed processes and water quality - Case study in Hokkaido, Japan (Contributing author: Hideaki Shibata, Hokkaido University, Japan)

In northern cool-temperate region, winter climate is characterized as being cold and snow-dominated, with large seasonal fluctuations in temperature, precipitation (rainfall and snowfall) and stream discharge. The accumulation and melting of snowpack in winter influences the movement of water and the transport of various solutes from soils to surface waters. Long-term trends in snowpack depth observed in Hokkaido suggest that climate change can influence watershed biogeochemical processes and water quality in northern Japan through complex interactions between winter climate and snowpack dynamics. The importance of snowmelt in affecting surface water biogeochemistry has been emphasized especially from studies in North America (Williams and Melack 1990; Hornberger et al. 1994; Campbell et al. 2007), indicating that flushing of solutes from snowpack and surface soil and dilution by snowmelt water and groundwater are major driving factors in affecting the concentration and fluxes of major solutes, particularly nitrate and DOC.

The early phase of snowmelt flushes solutes from the forest floor and mineral soil, contributing to episodic acidification and increased nutrient concentrations in surface waters (Baird et al. 1987; Piatek et al. 2005). The loss of nitrate is notably greater during snowmelt compared to other hydrological events associated with high precipitation inputs in the summer (Christopher et al. 2008). Anthropogenic activities including acid deposition and nutrient additions to surface waters have been shown to amplify acidic episodes and the eutrophication of surface waters in the northeastern US and Scandinavia (Baird et al. 1987; Chen and Driscoll 2005). Few studies in Northeast Asia, however, have evaluated the importance of hydrologic events in affecting surface water chemistry. It is assumed that different climatic, geologic and biological characteristics in Asian regions may result in different chemical response patterns than those observed for North America and Europe (Ohte et al. 2001).

In Japanese archipelago, parent materials are often associated with volcanic activity. These substrates have relatively high weathering rates and result in high concentrations of base cations in soil and drainage waters (Nakagwa and Iwatsubo 2000; Shibata et al. 2001). These high concentrations of base cations generally result in surface waters with little evidence of increased acidification in response to elevated acid deposition. An intensive monitoring study of stream chemistry in a headwater forested watershed on Tertiary Andesite in northern Japan (Shibata et al. 2002) showed relatively large fluctuations of stream discharge and ionic concentration but little change in pH (from ~7.0 to 7.7 during the snowmelt period). During snowmelt the dominant solutes were bicarbonate and base cations that represent high acid neutralizing capacity against snowmelt flushing of acids. At this same site plot-scale investigations also showed that the snowmelt dominated solute exports (Ozawa et al. 2001). Nakagwa and Iwatsubo (2000) and Koshikawa et al. (2007) have reported that many Japanese streams have elevated base cation concentrations and circumneutral pH values. Relatively high weathering rates might play an important role in explaining different watershed responses to acid deposition compared to Europe or North America.

Stream chemistry patterns also show spatial differences attributable to chemical and topographic features of a watershed. Ogawa et al. (2006) investigated that the relationship between the basin topography and stream chemistry for a series of nested watersheds in northern Japan. Those catchments with steeper hillslopes and relatively narrow basins were sources of nitrate, whereas riparian areas with gentle slopes and wider basin retained nitrate. The topographic index (a measure of potential wetness and hydrologic flow paths; Mitchell 2001) as well a vegetation patterns (Xu and Shibata 2007) were good predictors of nitrate and DOC concentrations in stream waters.

Recent studies using chemical analyses and isotopic tracers have indicated that the most of nitrate in surface waters is derived from soil microbial nitrification with little nitrate derived directly from atmospheric deposition (Burns and Kendall 2002; Christopher et al. 2008). Nitrate accumulated in surface soil is affected by soil temperature and moisture conditions. Recent studies have suggested that winter microbial processes beneath the snowpack are also a substantial contributor for solute leaching and gaseous emissions (Brooks et al. 1996; Monson et al. 2006).

Many climate change scenarios implicate that the regimes of temperature and precipitation in winter are changing in northern cool-temperate region (Likens 2000; Stottlemyer and Toczydlowski 2006). The change of snowfall and temperature will alter soil temperature, moisture and freeze-thaw regimes, which in turn have impacts on many hydro-biogeochemical processes affecting the production and transport of solutes in soils and stream waters (Mitchell et al. 1996; Park et al. 2005). Snow manipulation studies have found that soil freezing has strong impact on belowground processes especially with respect to influences on fine root mortality and subsequent diminishment of nutrient uptake by trees (Groffman et al. 2001; Nielson et al. 2001; Fitzhugh et al. 2001, 2003). Christopher et al. (2008b) conducted reciprocal transplants of surface soil for field incubation between northwestern (with dense snowpack and unfrozen soil) and eastern (with less snowpack and frozen soil) Hokkaido Island of northern Japan. The net nitrogen mineralization in surface soil collected in unfrozen region with dense snowpack was enhanced by the freezing, suggesting that the freezing of soil increased the production of labile organic nitrogen from microbial biomass and fine roots.

Long-term analyses of meteorological data have indicated that winter climate in Northeast Asia have changed towards warmer temperature and/or less snowfall (Jhun and Lee 2004; Hosaka et al. 2005; Suzuki 2006). Less snowfall will decrease the heat insulation by snowpacks and can lead to lowered microbial activity under colder soil temperature. Although lowered microbial activity under thinner snowpacks might be expected to lead to a slowed turnover of nitrogen and carbon in soil and hence a reduced nutrient leaching, experimental evidence suggests that enhanced freeze-thaw cycles under thinner snowpacks, particularly in early and late winter, are more likely to increase the pools of nitrogen and carbon from microbial biomass and fine roots that are available for snowmelt flushing in late winter and early spring.

Effects of summer monsoon rainfalls on watershed biogeochemical processes and water quality: Case study in Lake Soyang Watershed, Korea (Contributing author: Bomchul Kim, Kangwon Natioanal University, Korea)

Under a strong influence of the East Asian summer monsoon, over one-half of the annual rainfall in Korea is concentrated in the summer monsoon season from July through August. Usually several typhoons pass through Korea in a summer, accompanying large rain events. Rainfall rates in summer can often exceed 100 mm day^{-1}, and a few rain events can account for a substantial portion of the annual runoff. In contrast, base stream flow contributes very little to the annual transport of water and nutrients. For moderate rain events with < 50 mm rainfall, especially during dry seasons, most of rain water percolates into dry soil with little increase in discharge.

Large reservoirs, such as Lake Soyang, are filled with storm runoff water in summer, and the water level rises rapidly up to 30 m. Following the peak flow in summer, water level goes down as water is used in the downstream metropolitan area. Recent trends of precipitation and temperature in Korea have been linked to regional climate change. In LSW summer precipitation has been increasing at the rate of 10 mm yr^{-1} over the last three decades, with an average annual precipitation of 1,086 mm yr^{-1}. However, the total number of rainy days has remained the same, resulting in an increase of rain intensity. Even though air temperature has increased with a potential increase in evapotranspiration, these higher precipitation inputs have resulted in greater surface runoff (Yang 2007). Such increases can result in greater exports of both particulate and soluble materials from the watershed.

The rate of agricultural production per area has been sustained at a high level in Korea due to the shortage of arable flat land. The export rate of nutrients, especially phosphorus per unit area, from agricultural lands is higher than for other countries, with ~85% of phosphorus derived from fertilizer and animal manure (Kim et al. 2001). Nutrient discharge from agricultural areas is a major cause of eutrophication and deterioration of water quality in downstream reservoirs in Korea (Kim et al. 2001).

Lake Soyang, which is the deepest and largest reservoir in South Korea, is located in a sparsely populated mountainous region in the northernmost province of South Korea. The watershed has an area of 2,700 km^2, with 90% of the watershed covered with forests and only 4.8 % used for agriculture. Nevertheless, the agricultural fields export large amounts of nutrients due to the high rate of application of agricultural fertilizer and pen-type livestock farming, causing eutrophication of the reservoir. The main inflowing tributary, the Soyang River, contributes 90% of the total water into Lake Soyang. The watershed has only a few small rural towns with 42,000 residents and few sources of industrial sewage.

Although forests are the dominant land use type in LSW, there are two “hot spots” of agricultural nonpoint source pollution, with substantial impacts on the trophic state of Lake Soyang and downstream reservoirs. One of the hot spots is the watershed of the Mandae Stream, which flows into the Inbuk River, a tributary of the Soyang River. The watershed of the Mandae Stream is a bowl-shaped basin in which intensive agriculture has dramatically transformed the otherwise heavily forested landscape into a basin with expanding arable lands and marginal forests along the mountain ridges. The area of the watershed is 61.8 km^2 and 16% is cultivated area where mainly vegetables are grown. The second “hot spot” of nonpoint source pollution is the watershed of the Jawoon Stream where highland agriculture is active and runoff water is very turbid due to high sediment loads derived from intensive tilling on steep hillslopes (Jung et al. 2008).

Recently the concentrations of nutrients and suspended solids have been monitored at the outlet of the Mandae Stream and the Soyang River. The discharge rate of the Soyang River varied markedly < 10 to > 4,000 m^3 s^{-1}, and the water quality also varied with it. High flow rates in rivers have been linked to the increases in particulate matter concentrations (Kim et al. 1995; Campbell et al. 2000). In the Soyang River, the concentrations of phosphorus and suspended sediment increased dramatically during rainfall events. The concentrations of total phosphorus (TP) increased from 0.01 to 1.5 g P m^{-3} with a concomitant increase in flow rate.

The highest concentrations of TP and suspended solid (SS) in the Soyang River occurred in the early rising phase of rain events. Particulate phosphorus was the predominant form of transported phosphorus, although soluble reactive phosphorus concentrations were also high in storm runoff. Several episodic events in a year comprised the bulk of the annual phosphorus loading. Contrary to phosphorus, the concentrations of total nitrogen (TN) showed substantially less variation in the range of 0.9 to 3.8 g N m^{-3}, with 90% of TN as the form of nitrate.

The water quality in the Soyang River showed much higher phosphorus, nitrogen, and suspended sediments than Lake Soyang and other nearby rivers. The volume-weighted mean of TP was 0.20 – 0.24 g P m^{-3}, which was much higher than the threshold level of eutrophication, contributing to the increase of phosphorus in summer in Lake Soyang and its downstream reaches. Suspended sediments in the range of 200-530 g m^{-3} contributed to the deterioration of stream habitat and also resulted in high turbidity in Lake Soyang (Kim and Jung 2007). Because the thermal stratification is very stable in Lake Soyang and the inflowing storm runoff water is colder than the epilimnion, turbid storm runoff flows into the metalimnion of the reservoir, forming an intermediate layer of high turbidity and phosphorus content. The turbid water in the intermediate layer is discharged from the reservoir through an outlet located at the middle of the dam, further transporting turbidity downstream for up to three months.

The major source of phosphorus export on rain events is agricultural fields; organic compost or manure and chemical fertilizer. In Korea, the application rate of chemical fertilizer is relatively high, and this rate has increased from 230 kg ha^{-1} yr^{-1} in 1980 to 450 kg ha^{-1} yr^{-1} in 1994 (Shim 1998). In addition, instead of raising cattle on pastures pen-type livestock farming using imported animal feed is common in LSW, resulting in large amount of nutrient inputs into the watershed (Kim et al. 2001). Intensive tilling activities in highland vegetable fields make steep hillslopes more vulnerable to erosion under increasing amount and intensity of monsoon rainfalls. Since the amount and intensity of summer monsoon rainfalls are projected to continue to increase in the Korean Peninsula, the export of nutrients and other pollutants from the watersheds will increase in proportion to the amount and intensity of precipitation, posing a major challenge in the management of agricultural soil fertility and surface water quality.

Coupled effects of climate variability and acid deposition: Case study in Chongquing, China (Contributing author: Lei Duan, Tsinghua University, China)

During the last fifty years, the annual mean temperature has increased at a rate of 0.022°C yr^{-1} in China (Ren et al. 2005). Over the same period, the annual mean precipitation has decreased by 50-120 mm in east of Northeast China, central and south of North China, and east of Southwest China, but increased by 60-130 mm in the north of Northeast China, west of Southwest China, and large areas in Northwest China, East China and Southeast China (Ren et al. 2005). Regional climate models predict that the temperature might increase by 2.2-3.0°C at the end of 21st Century (Gao et al. 2003).

In China more attention has been paid to the effects of climate change on the supply of water resources rather than on water quality (Ren 2008). It is likely that water pollution and land use change will have more marked effects on water quality in many parts of China due to urbanization and intensive agricultural activities. In arid areas in northwest China increasing temperature has accelerated the melting of glaciers. This, combined with increased precipitation, has resulted in an increase of runoff and a decrease of salinity and hardness of some inland waters (Fan et al. 2005; Dang et al. 2006; Arkin et al. 2007). Some studies, however, have shown that prolonged draughts have increased the salinity of waters in northwest China (Tan et al. 2001; Chen et al. 2006). The increased precipitation in humid regions of east China, especially in the Yangtze River basin, has been linked to the reduction of solute concentrations but an overall increase in solute drainage loss (Xia et al. 2000; Zhang and Chen 2000).

The issue of “acid rain” has gained considerable attention in China over the last decade (Hao et al. 1998 and 2001), because emissions of acid rain precursors (SO_2 and NO_x) have been increasing drastically in recent years. There are important interactions between climate change and acidic deposition including the suggestion that recovery of surface waters from acidification may be delayed by climate change due to reductions in the total amount of precipitation in the summer, or more frequent storms in the winter (Aherne et al. 2006; Evans et al. 2007; Laudon 2007).

The effects of acid deposition on five forested watersheds in Southern China and Southwestern China were monitored from 2001 to 2004 in a Sino-Norwegian collaboration project entitled “Integrated Monitoring Program on Acidification of Chinese Terrestrial Systems” (IMPACTS) (Larssen et al. 2004). The monitored watersheds include Tieshanping in Chongqing province, Luchongguan and Leigongshan in Guizhou province, Caijiatang in Hunan province, and Liuxihe in Guangdong province. Precipitation, throughfall, soil water, and surface water chemistry at these sites have been monitored. Among the five IMPACTS sites, Tieshanping watershed in Chongquing province in southwestern China is under the most severe impacts of acid deposition, with 40-50% defoliation and maximum 6% tree death of masson pine (Larssen et al. 2004). The annual mean precipitation has decreased by about 10% over the past 50 years and is projected to continue to decrease in future (Ren et al. 2005; Gao et al. 2003).

At Tieshanping high amounts of precipitation in summer and autumn were associated with lower sulfate concentration in precipitation, whereas in the winter and spring sulfate concentrations were higher. The seasons with higher precipitation coincided with lower sulfate concentrations in soil water. The seasonal patterns of calcium concentrations were similar as those of sulfate. Unlike sulfate and calcium, high precipitation in summer and autumn did not always lead to lower concentrations of total inorganic nitrogen (TIN, mostly nitrate) in soil water, presumably because hot and moist conditions in the subtropical region in China accelerated N mineralization in soil. Similarly, high nitrate concentrations have also been found in some Japanese watersheds during the summer, a period with high temperatures and high precipitation (Ohte et al. 2001; Ohrui and Mitchell 1997). The pH values in throughfall were lower in the winter and spring compared to the summer and fall. The average pH of surface water was ~5.0 and much higher than that of soil water (~4.0), suggesting the importance of buffering processes in deep soil and bedrock.

Interannual variations in surface water quality were different from the seasonal patterns observed. The pH of surface waters was lower and the concentrations of

SO_4^{2-} and NO_3^- higher in the wet year of 2002 than during the dry years of 2001 and 2003. The export of SO_4^{2-} and NO_3^- in stream waters draining the watershed tended to be higher in the wet year (2002) than in the dry years (2001 and 2003). The results suggest that decreases in precipitation can moderate the impacts of acid deposition on surface water acidification and nitrate leaching from the acidified forest ecosystem.

Summary and future research needs

Despite large spatial variations, increasing variability and extremes in precipitation, along with climatic warming, have been observed across Northeast Asia. In northern latitudes, as shown in the case study in Hokkaido, Japan, winter snowpack dynamics and soil freeze/thaw cycles play a pivotal role in the release of acids and nutrients from steep hillslopes, with soil and surface water acidification buffered by soils rich in base cations. In southern Korean Peninsula, increasing amount and intensity of summer monsoon rainfalls, in combination with land use change and steep topography, have contributed to water quality deterioration by increased sediments and nutrients in the downstream rivers and reservoirs that supply potable water to a metropolitan population exceeding ten million people. In many parts of the southern China, lower precipitation with large year-to-year variations have been observed in recent years. This variability in precipitation appears to have had a substantial influence on year-to-year variations in acidity and nutrient fluxes in soils and stream waters of forested watersheds under increasing levels of acid deposition.

Unique features of watershed geomorphology and biogeochemistry in Northeast Asia require innovative approaches to better understand watershed biogeochemical responses to climate change and variability and their environmental implications. Priority should be placed on the biogeochemical study of terrestrial export of sediments and nutrients from steep mountainous watersheds. Flashy hydro-biogeochemical responses to extreme rainfall events need to be addressed with novel research approaches paying more attention to patterns associated with these events. A combined approach of linking modeling with field monitoring of biogeochemical processes and environmental controls will be needed to better predict the response of ecosystem functioning and services to future climate change. Another challenge would be spatial extrapolation of the results from case studies to national to regional scales. In this regard, development of integrated tools combining GIS spatial analysis and satellite remote sensing for watershed biogeochemical studies need to be further developed for Northeast Asia to aid watershed management and evaluation of climate-related risks to water quality.

3.2. Overview of climate change impacts on surface water quality in Southeast Asia – Synthesis of results from the first and second workshop

The Lower Mekong River Basin

The Lower Mekong River (LMR) provides water resources for over 60 million people living in the LMR basin. Fast growing populations and rising water demand constitute a major threat for the sustainable management of water resources in the region. Considering extremely high seasonal variability in precipitation and runoff, potential changes in monsoon rainfall regimes across the region will put additional pressures to the sustainable supply of clean water for both domestic purposes and economic activities. There have been rare efforts to explore the potential effects of changing climate on water resources in the region, their quality in particular.

The Mekong River Commission has monitored the water quality of most of River since 1985 with the participation of Lao PDR, Thailand and Viet Nam, and from 1993 in Cambodia. The Water Quality Monitoring Network (WQMN) consists of 90 monitoring stations across Cambodia, Lao PDR, Thailand and Viet Nam. According to the results of WQMN, most of water quality parameters monitored except suspended solids (SS), N, P, and COD have shown neither spatial hot spots of water pollution nor clear temporal trends.

SS in the LMR are the results of soil erosion from both the upstream part of the river and natural and anthropogenic processes occurring with the Basin. Much higher concentrations of SS have been observed during the monsoon than the dry period at all WQMN stations. SS concentrations decrease downstream along the river during both seasons (Fig. 3.2.1), suggesting the dominant influence of sediments eroded Tibetan Plateau and upstream regions in China.

Long-term monitoring data have shown that SS concentrations along the upper part of LMR have recently been decreasing, probably due to the construction of large dams and revegetation in China (Fig. 3.2.2). Some recent studies have also reported that the construction of Manwan Dam on the Upper Mekong River in 1993 has resulted in significant reductions in sediment flux at downstream locations such as Chiang Saen, Thailand (Lu and Siew, 2006; Kummu and Varis, 2007), despite contradictory studies reporting no pronounced dam effects.

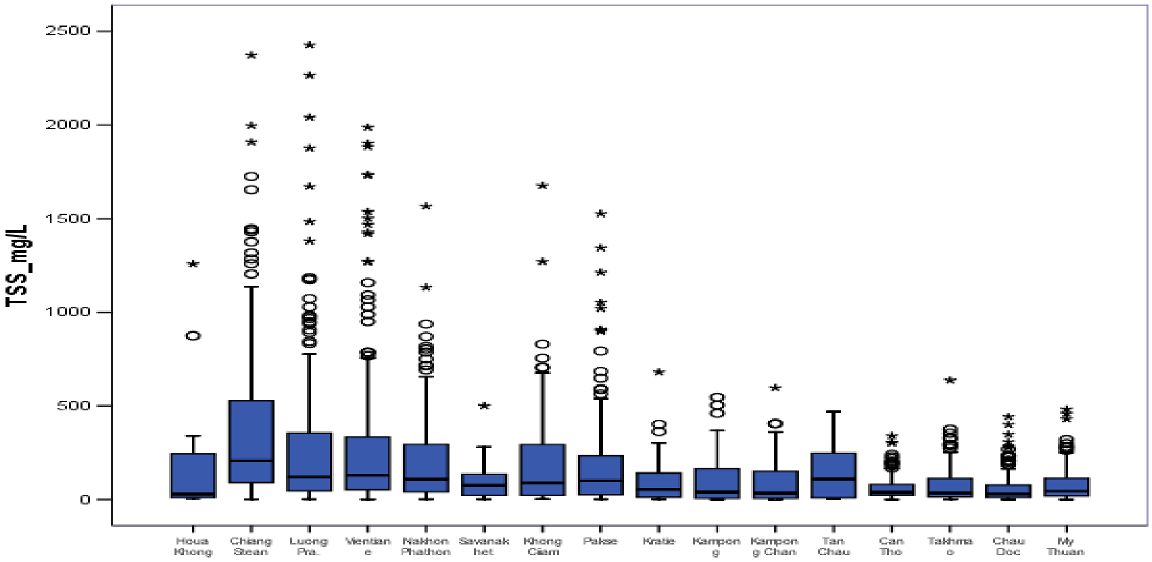


Fig. 3.2.1. SS concentrations at major WQMN stations along the LMR from upstream to downstream (Source: Khoi, 2007).

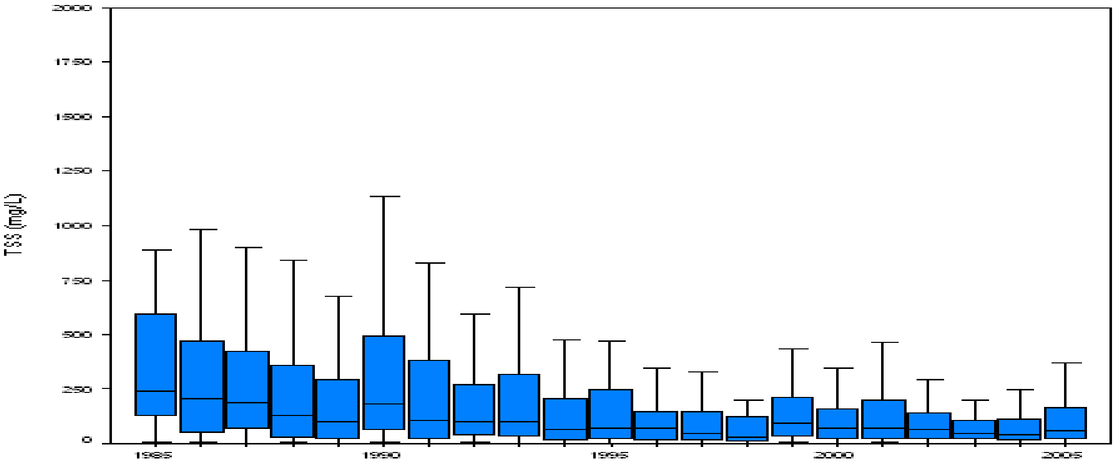
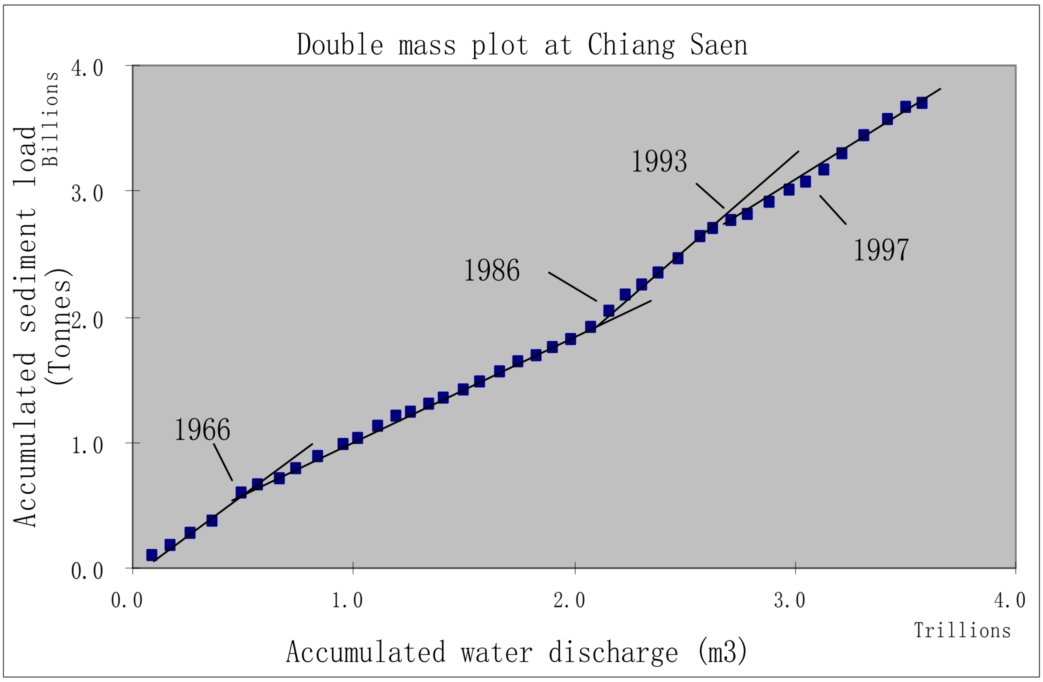


Fig. 3.2.2. Long-term temporal changes in SS concentrations at WQMN stations along the LMR for the period of 1985-2005 (Source: Khoi, 2007).

At the workshop, Lu and Wang (2007) pointed out that the lack of long-term high quality data, along with misinterpretation of monitoring data, represents a major challenge in evaluating dam effects on sediment loads along the LMR. Using double mass plot approach, they further suggested that climate variations had have also interactive effects on temporal variations in sediments loads, to a different degree depending on monitoring stations (upstream Chiang Saen vs. downstream Mukdahan station) and observation periods (1971-1986, 1987-1998 and 1999-2003)(Fig. 3.2.3). At Chiang Saen, for instance, humans and climate variations were assessed to have a positive (+8.97 Mt yr^{-1}) and a negative (-7.32 Mt yr^{-1}) impact on annual sediment load, respectively, compared to the baseline annual load for the period of 1962-1965 (90.54 Mt yr^{-1}).

In a recent report using its WQMN data collected during the period of 1996-2006, Mekong River Commission (MRC) concluded that water quality along the mainstem of LMR was “generally good or acceptable for protection of human health, aquatic life and agriculture” (MRC, 2007). While most water quality parameters were generally below contamination levels, slightly increasing trends have been found for total P and inorganic N at downstream WQMN stations over recent years. Since SS concentrations, a potent sorbent for organic forms of P and N, have been decreasing over the same period, recent increases of these nutrients might be related to expanding urban and intensive agricultural areas (Khoi, 2007).

There have been only a few attempts to link recent temporal patterns of water quality in the LMR to climate change and variability. In a statistical analysis of weather and water quality data from the MRC WQMN, Prathumratana et al. (2008) found positive correlations between hydroclimatic parameters such as precipitation and discharge and some of analyzed water quality parameters including TSS, NO_3^-, PO_4^{3-}, TP. During the workshop, potential effects of temperature changes on water quality have also been addressed. Water temperature in the LMR decreases downstream along the LMR and shows very strong seasonality between the monsoon and dry periods (Khoi, 2007). Although it was reasonably assumed that recent increases in air temperature could have effects on temperature-sensitive water quality parameters such as DO and BOD, no clear temperature effects on these parameters were found for two Mekong tributaries in Thailand, probably due to confounding effects of land use change and water pollution (Wirojanagud et al., 2009).



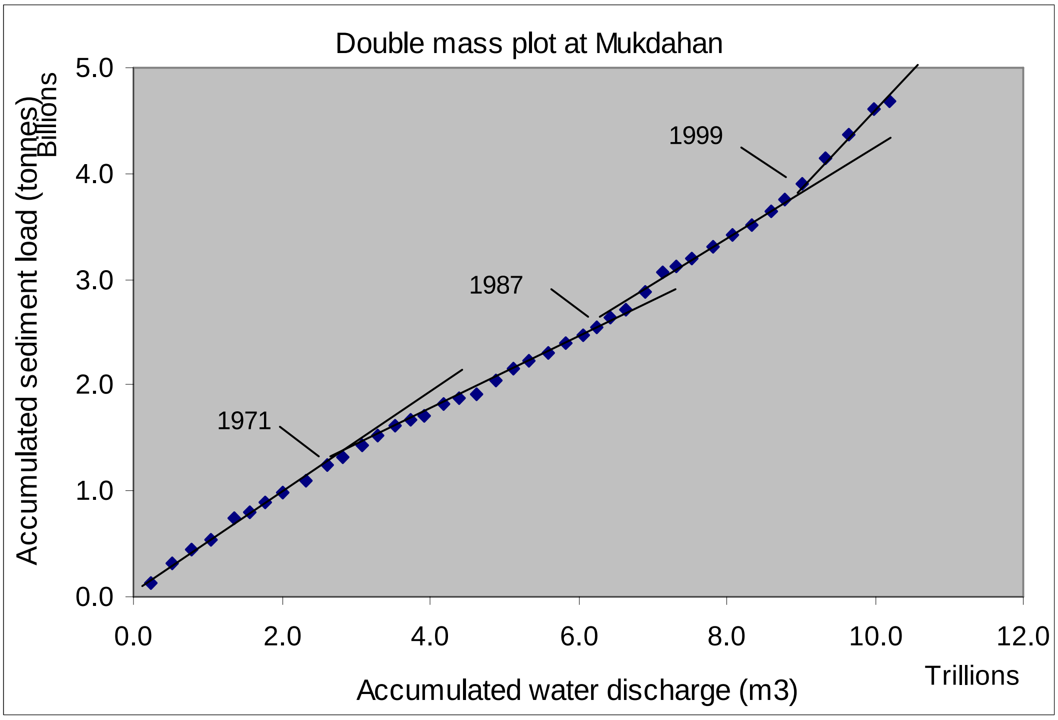


Fig. 3.2.3. Long-term changes in flow and sediment load at two WQMN stations along the LMR (Source: Lu and Wang, 2007)

Malaysian Borneo and Indonesia

Climate regimes in Borneo and other neighboring islands are distinctly different from those in other parts of SE Asia. Above all, seasonality in precipitation is not clear and hence the distinction between dry and rainy seasons is very weak or absent depending on locations. Compared to the northern latitudes, long-term patterns of warming have been relatively weak and no consistent patterns of precipitation have been observed in SE Asia in general, and Malaysia and Indonesia in particular (Cruz et al., 2007; Choi et al., 2009). During the first and second workshops, potential linkages between recent climate changes and water quality were evaluated. However, the lack of reliable long-term data, combined with complex patterns of climate change in the region, did not allow a generalization of climate effects on surface water quality in this region.

In Brantas River flowing through East Java, Indonesia, for example, decreases in DO at a polluted monitoring location have been observed over the last decade, concurrent with water temperature increases over the same period (Sarjiya et al., 2009). Considering substantial reductions in BOD and COD at the same location over the recent years due to water pollution control efforts, increased water temperature can be proposed as a potential contributor to the decreased DO. But this effect was not obvious for other monitoring locations. In addition, other water quality parameters such as ammonium have shown increases in concentration during the recent years. Runoff from newly expanded non-point sources was suggested as a possible explanation, pointing to a concurrent, and often overwhelming, influence of land use change.

3.3. Cross-site comparison of monsoon effects on seasonality in surface water quality – Results from the pilot study in 2006 and the first-year field monitoring in eight countries

Cross-site comparison of seasonal differences in surface water quality

Seasonal differences in water quality depended on parameters, sites, and years. Among measured water quality parameters, electrical conductivity, anions (Cl^- and SO_4^{2-}), UVA_{254} (a measure of dissolved organic matter), and TSS (a measure of suspended sediments) showed relatively clear seasonal differences between dry and wet period (Fig. 3.3.1). When data from 2006 and 2007/2008 sampling campaigns were pooled together for dry vs. wet period, around 80% of all sampling locations showed decreases in electrical conductivity and the concentrations of Cl^- and SO_4^{2-} during wet period relative to dry period, while the reversed trend was clear for UVA_{254} and TSS. No or less clear seasonality was observed for pH, NO_3^-, and NH_4^+.

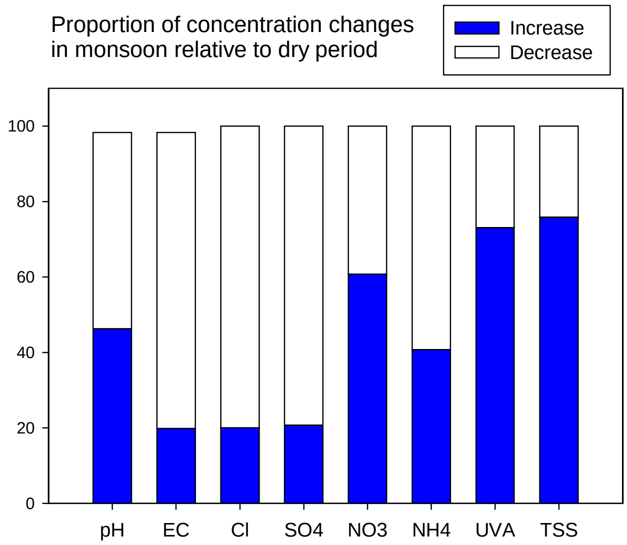


Fig. 3.3.1. Proportion (%) of sampling locations where concentrations of measured water quality parameters either increased or decreased during wet periods relative to dry periods of both 2006 and 2007/2008 sampling campaigns.

At most of sampling locations, electrical conductivity and the concentrations of Cl^- and SO_4^{2-} were generally lower during the wet period, suggesting a dilution effect of rainfalls on dissolved ions in surface waters (refer to Inam & Park in this volume for more details on data from 2007/2008 campaign). This rainfall-induced dilution was not evident for NO_3^- and NH_4^+ and monsoonal concentration increases in these nutrients were observed at many sampling locations, especially under influence of agricultural or urban runoff.

TSS was generally higher during wet period at most of sampling locations and monsoonal increases were more evident at the Thai and Lao watersheds along the upper reaches of the Lower Mekong River, which meanders through more steep terrain compared to the relatively flat areas along the downstream reaches. TSS also showed large year-to-year variations, with much higher concentrations observed for two Mekong watersheds in 2006 monsoon and for the Malaysian watershed in

2007-2008 wet period. These between-year differences might reflect rainfall amount and intensity of each sampling period.

UVA_{254} was generally higher during wet period at most of the monitored watersheds except Phnom Penh, Cantho, and Bogor. The well-established ‘hydrologic flushing’ of dissolved organic matter from terrestrial sources during storm events might have contributed to monsoonal increases in UVA_{254}. In the case of Phnom Penh, sampling locations along the Tonle Sap River flowing through huge wetland areas showed clear decreases in UVA_{254} during the wet period, during which the Mekong River reversed the flow of the Tonle Sap River. Since this monsoonal flow reversal can cause the water quality of the Tonle Sap River to be dominated by that of the Mekong River, dissolved organic matter exported from the riparian wetlands of the Tonle Sap River appeared to be diluted by reversed flow from the Mekong River.

Seasonality in metal concentrations in surface waters

Dissolved and total metal concentrations showed element-specific seasonal patterns (Fig. 3.3.2). For Al, Co, Fe, and Pb, total concentrations (measured as acid-recoverable metals) were much higher than dissolved-phase concentrations, especially during wet period. For Sr both dissolved- and total-phase concentrations were higher during dry period at all monitored watersheds. In most cases, dissolved-phase concentrations comprised the bulk of total-phase Sr concentrations, as indicated by the proximity between average dissolved and total-phase concentrations. This monsoonal decrease in metal concentrations was also observed for As, Li, Mn, Ni, and U, but to a different degree among sites and between the dissolved- and total-phase concentrations.

For those metals that showed clear concentration increases during wet period (Al, Co, Fe, and Pb; Fig. 3.3.2), the positive relationships between TSS and total metal concentrations were much stronger during the wet periods for both 2006 and 2007-2008 sampling campaigns (Fig. 3.3.3). Total Sr concentrations exhibited very weak positive relationships with TSS concentrations during dry period and no relationship during wet period, suggesting that other factors than suspended sediment control Sr concentrations in surface waters. For those metals that showed mixed seasonal patterns (As, Li, Mn, Ni, and U), the relationships between TSS and metal concentrations were weakly to moderately positive during wet period.

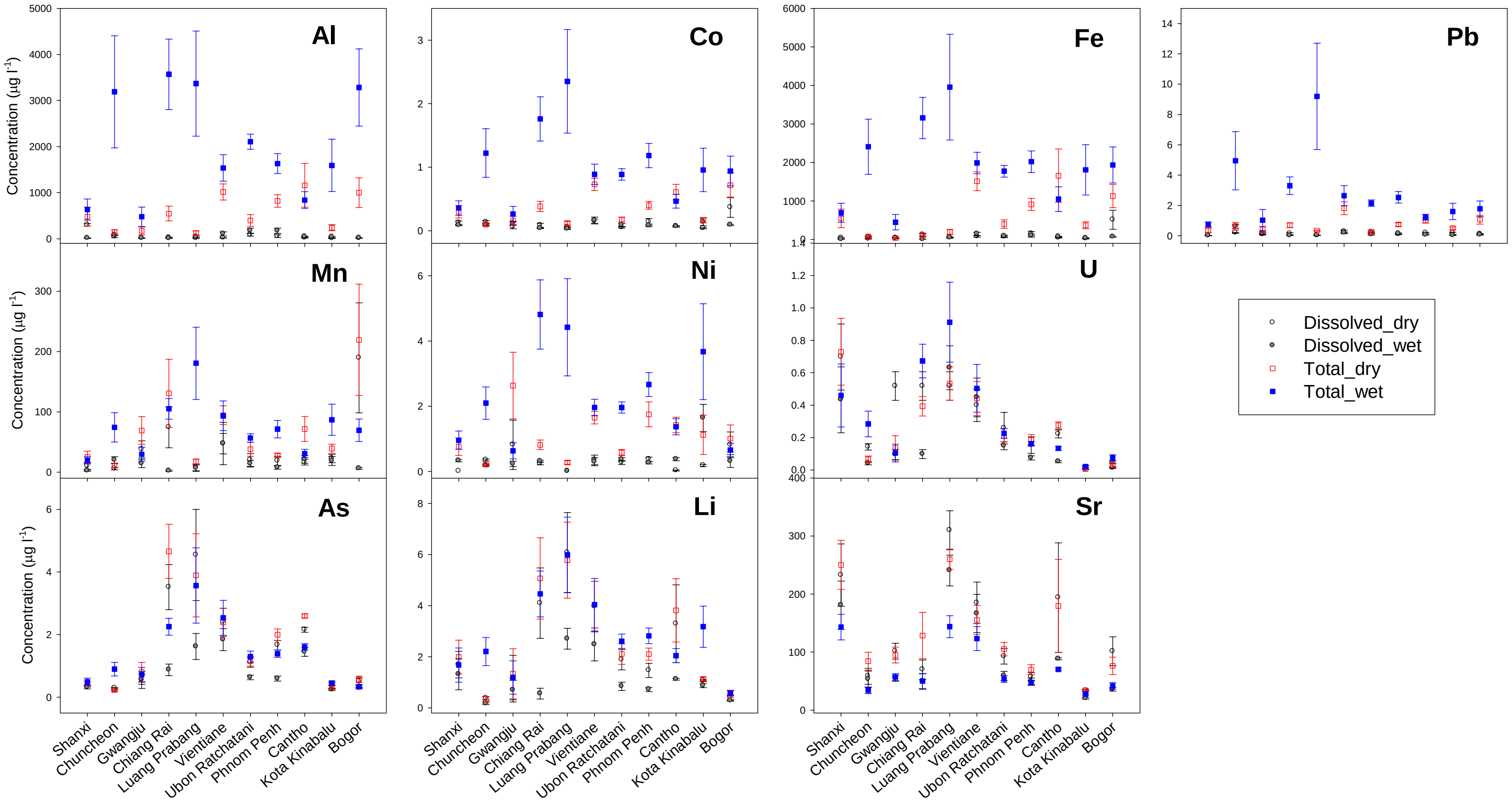


Fig. 3.3.2. Seasonal differences in mean concentrations of dissolved and total metals between dry and wet periods at 11 watersheds monitored in 2006 and 2007/2008 sampling campaigns (symbols are mean ± 1SE).

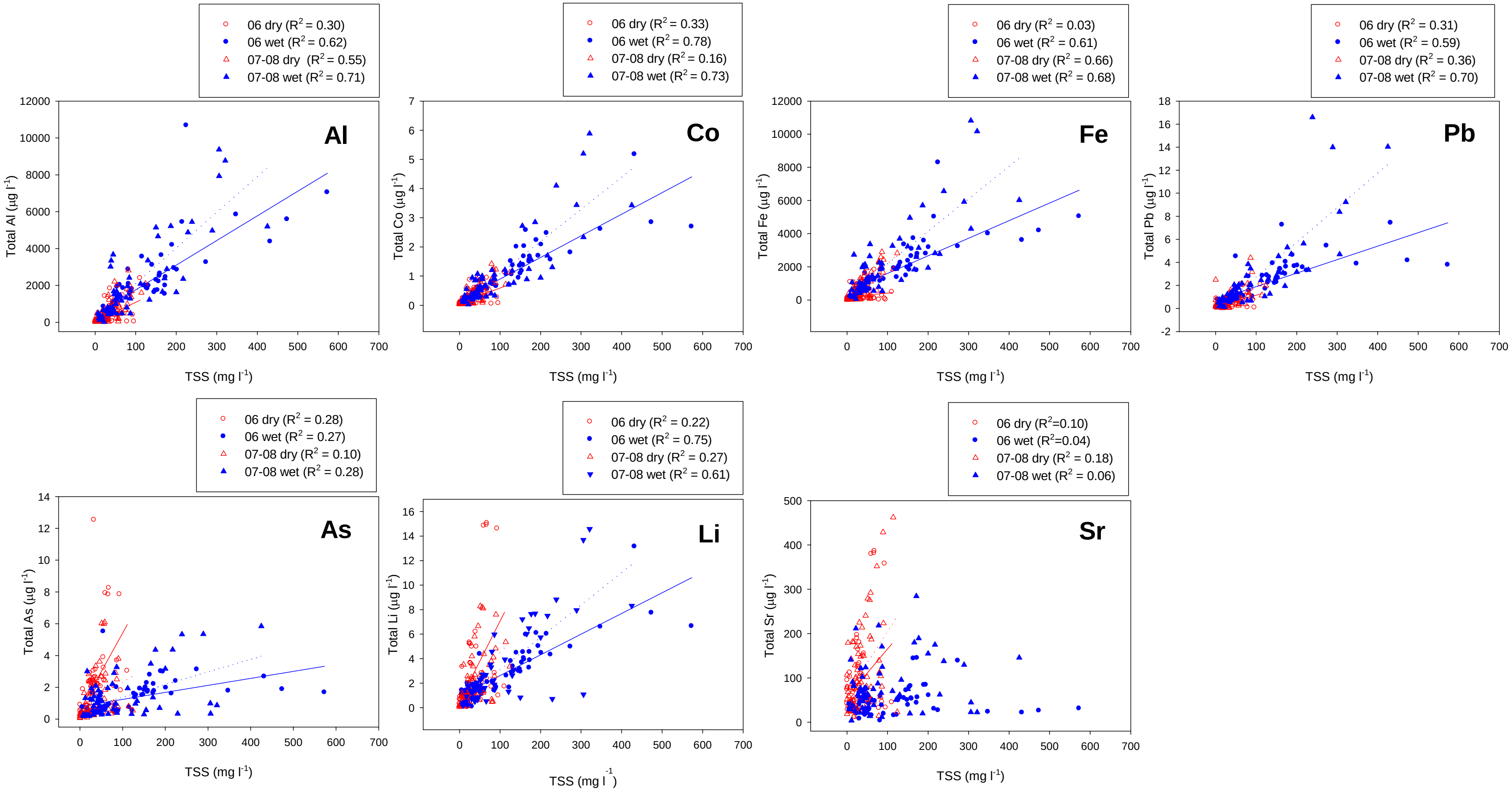


Fig. 3.3.3. Relationships between TSS and total metal concentrations during each dry vs. wet period of 2006 and 2007/2008 sampling campaigns. Significant positive relationships are indicated by best-fit regression lines through each plot.

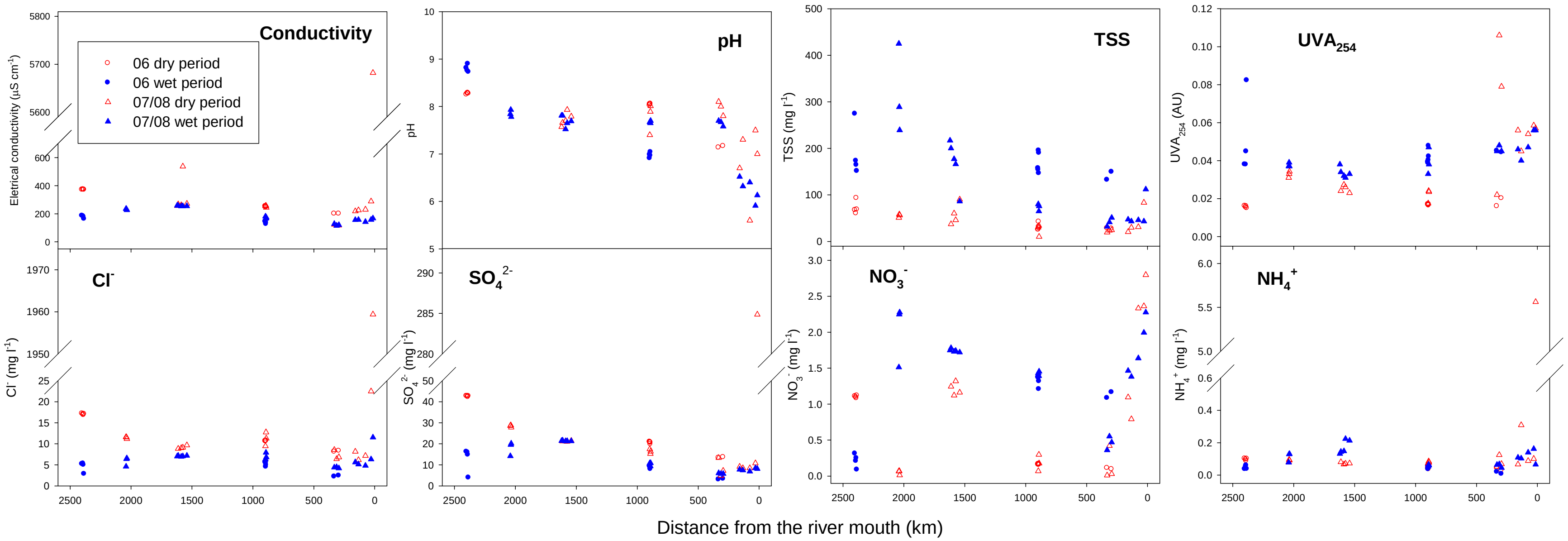


Fig. 3.3.4. Changes in concentrations of measured water quality parameters along the Lower Mekong River from Chiang Rai to the river mouth in the Mekong Delta.

Seasonality in water quality in the Lower Mekong River

Seasonal differences in water quality observed for the whole sampling sites became more evident when compared along the Mekong River from the most upstream site to the river mouth (Fig. 3.3.4). Electrical conductivity and the concentrations of Cl^- and SO_4^{2-} were lower during wet period for both 2006 and 2007-2008 campaigns and tended to decrease towards the river mouth, although during dry period extremely high values were observed at the most downstream site 15 km away from the sea, indicating the influence of seawater intrusion.

TSS concentrations and UVA_{254} were higher during wet period along the river except the reaches downstream of Phnom Penh where UVA_{254} was higher during the dry period probably due to the contribution of organic matter-rich Tonle Sap River at Phnom Penh and irrigation waters draining agricultural lands in the Mekong Delta. The concentrations of NO_3^- and NH_4^+ and pH showed not consistent seasonal patterns, pointing to the importance of local sources in determining the contamination of river waters with nutrients associated with agricultural or urban runoff.

Summary and implications

Some of measured water quality parameters showed clear seasonality, including lowered electrical conductivity and anion (Cl^{-1} and SO_4^{2-}) concentrations and increased concentrations of suspended sediments and dissolved organic matter during wet period. This result suggests that increased rainfalls during wet season can increase terrestrial inputs of suspended sediments and dissolved organic matter from various non-point sources, while increased streamflow leads to in-stream dilution of some chemicals having limited inputs via surface runoff. Increased suspended sediments during wet period coincided with increases in concentrations of some of measured metals (Al, Co, Fe, and Pb), suggesting the role of suspended sediments in determining the fate and speciation of metals in surface waters. The similar seasonal patterns were observed along the Lower Mekong River. Comparison of seasonal patterns among 11 monitored watersheds having distinct topographic and land use features and between two sampling campaigns at three watersheds suggested vulnerability of water quality in watersheds undergoing rapid land use change, especially in wetter years. More time-intensive and spatially extensive monitoring will be needed to obtain additional data essential in assessing risks of water quality deterioration associated with climate change and variability

3.4. Short-term changes in surface water quality in response to climate variability and extremes – Results from the second-year intensive monitoring

Short-term responses of sediment and metal export from Punch Bowl Watershed to monsoon rainfall events

In Punch Bowl Watershed, sediment export from both steep forest hillslopes and downhill croplands rapidly increased in response to increasing rainfall and runoff during each storm event, with larger responses observed in the agricultural stream and during more intense events (Fig. 3.4.1). While suspended sediment measurements in combination with real-time turbidity monitoring in the forest stream also showed a rapid increase in sediment export from small to extreme events, suspended sediment concentrations were much higher in the agricultural stream.

Short-term changes in the concentrations of dissolved organic carbon (DOC) and particulate organic carbon (POC), along with dissolved nutrients (data not shown), in the forest and agricultural streams matched temporal variations in discharge during the monsoon rainfall events (Fig. 3.4.1). The response of POC was non-linear from small to extreme events and stronger than DOC during more intense events. In the agricultural stream the response of POC was not proportional to rainfall amount and intensity, implying variable response in the export of low-carbon sediments from croplands.

Silt-size sediments were prevalent during the peak flow of each storm, particularly in the agricultural steam. During the fourth event, which was the most extreme among four storm events, TSS was 10-fold higher in agricultural stream than in forest stream (Fig. 3.4.2). Given small differences in POC concentrations between the sites (Fig. 3.4.1), silts from croplands appear to have disproportionately lower carbon contents.

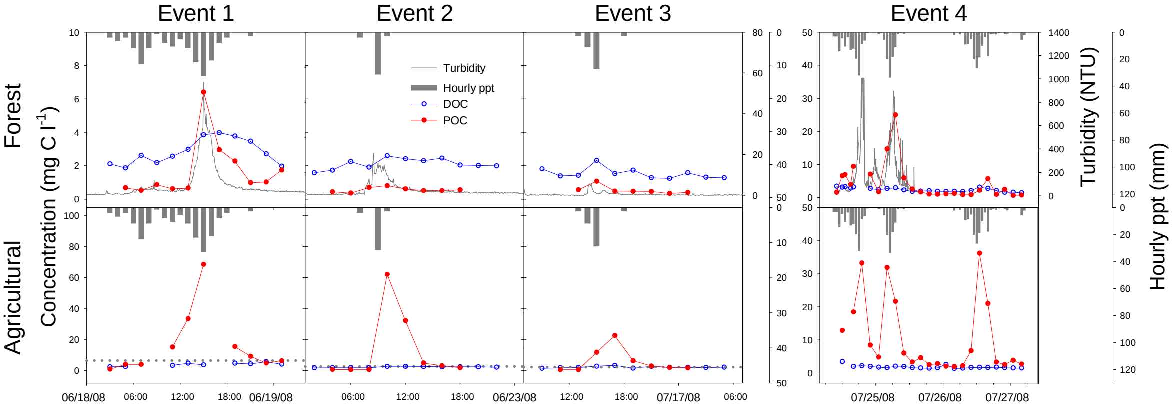


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Fig. 3.4.1. Short-term changes in turbidity and the concentrations of POC and DOC in the forest and agricultural “Mandae” stream during four storm events from late June through July, 2008.

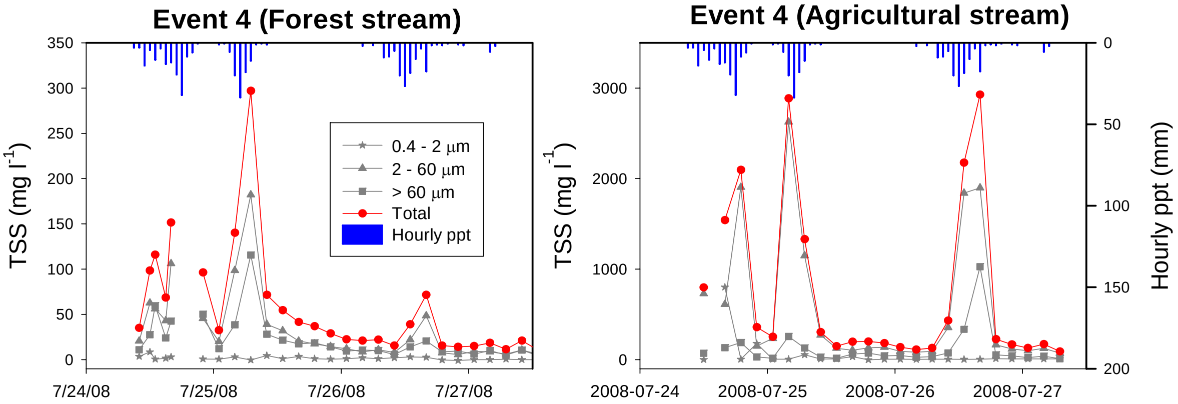

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Fig. 3.4.2. Short-term variations in the total and three particle size fractions (sand, silt and clay) of suspended sediments in the forest and agricultural streams during the most extreme event in 2008.

For all measured metals except Sr, concentrations of particulate metals were much higher than the dissolved phase and particulate metal concentrations peaked during the peak flow (Fig. 3.4.3). During the most extreme event (total precipitation over 400 mm in 3 days), the highest concentrations of particulate metals in both streams were associated with silt-size sediments (2 – 60 µm), followed by sand (> 60 µm) and clay (0.4 – 2 µm). Silt-associated metals comprised the bulk of metal concentrations in the agricultural stream, pointing to the dominance of silt-size sediments eroded from the agricultural fields.

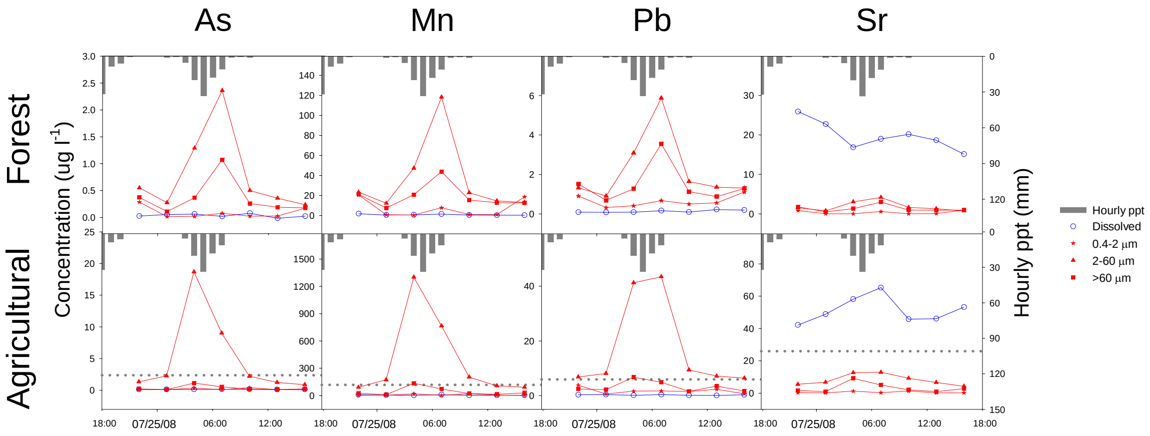

Fig. 3.4.3. Short-term variations in concentrations of dissolved and particulate phases of 4 selected metals in a forest & a downstream agricultural stream during an extreme rainfall event. Particulate metals were differentiated by 3 sediment size ranges (0.4-2 µm, 2-60 µm & >60 µm).

<u>Scale-dependent responses of suspended sediments in Khan & Mekong River watersheds in Lao PDR</u>

Turbidity in both Mekong and Khan River gradually declined after the extreme flooding in early August, 2008, reflecting a relatively slow response of sediment export from large watersheds upstream of the measurement locations (Fig. 3.4.4). Turbidity in Mekong River, either upstream or downstream of the confluence with Khan River, was much higher than along the mouth of Khan River both before and after the flooding event. Compared to small differences in turbidity in Mekong River around the peak flow, turbidity changes along the Khan River mouth to the confluence were more rapid, suggesting more rapid responses of sediment release from a smaller watershed area of Khan River than Mekong River that integrates sediment exported from a much larger land area with highly erodible steep terrains, particularly along the Upper Mekong River Basin.

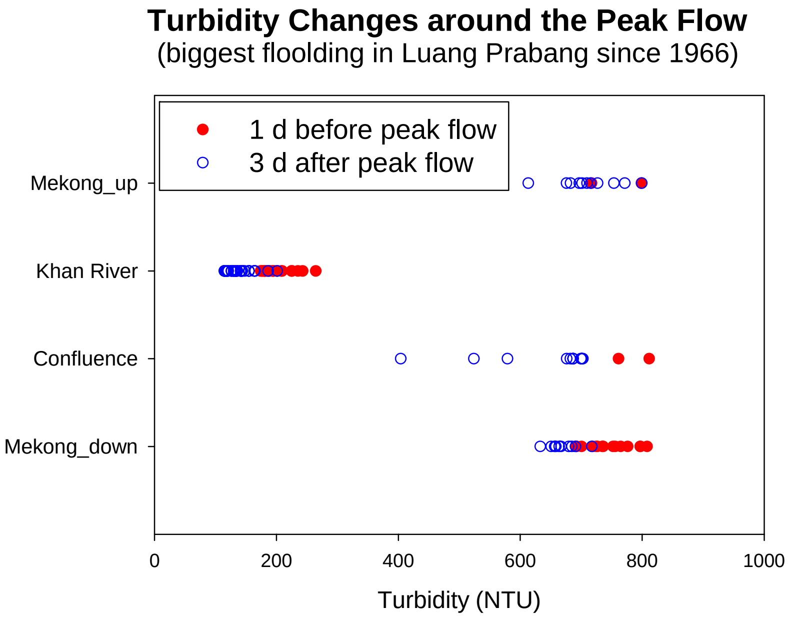

Fig. 3.4.4. Changes in turbidity along the cruised reaches of Mekong & Khan River around the peak flow on August 12, 2008, during the 40-year flooding event in Luang Prabang.

For four days immediately after the peak flow of the flooding event on August 12, a stream draining a small agricultural watershed was monitored for changes in turbidity. The real-time turbidity monitoring showed very low turbidity one day after the flooding peak and transient turbidity increases during a small rainfall event (<10 mm d^{-1}) on the following day (Fig. 3.4.5). Compared to turbidity values in Mekong and Khan River around the peak flow (Fig. 3.4.4), the transient but extremely high values recorded during the small event suggest flashy responses of sediment export from the small agricultural watershed converted from forests on steep hillslopes.

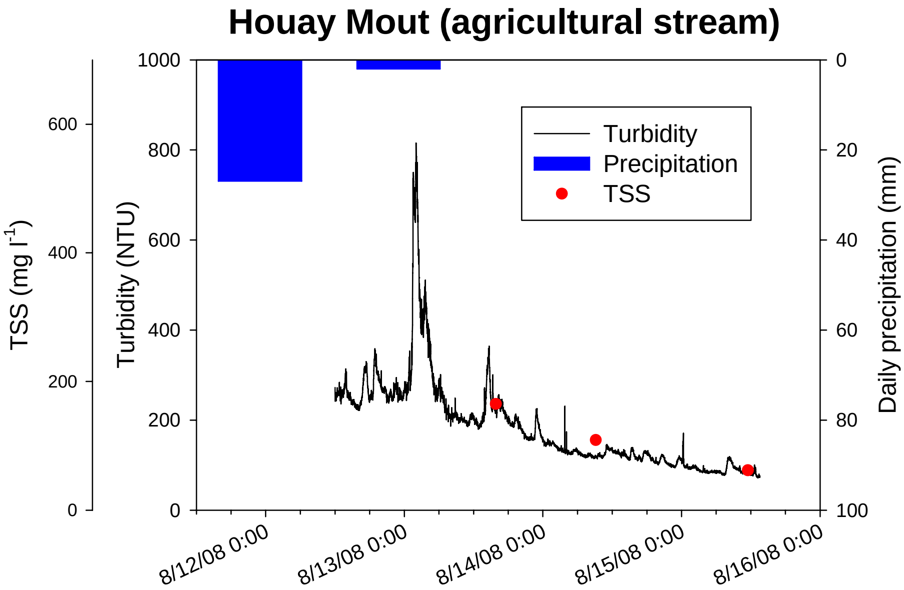

Fig. 3.4.5. Changes in turbidity and TSS concentrations (mg l^{-1}) in Mout Stream draining a small agricultural watershed after the peak flow on August 12, 2008 during the 40-year flooding event in Luang Prabang.

Simultaneous daily water sampling at three different types of surface waters (Khan River and agricultural vs. forest stream) allowed a comparison of sediment export from lands of different size and land use. At all three sampling locations, daily changes in TSS concentrations showed responses of suspended sediment to recurrent rainfalls over the two-week sampling period (Fig. 3.4.6). While TSS concentration in Khan River were generally higher than in two smaller streams, concentration changes in response to rainfalls were slower and smaller, especially compared to drastic increases in the agricultural stream following the four days of consecutive rainfalls. By comparison, TSS concentrations in the forest stream were generally lowest throughout the sampling period and their responses to rainfalls were smallest, suggesting a low erodibility of the forested watershed.

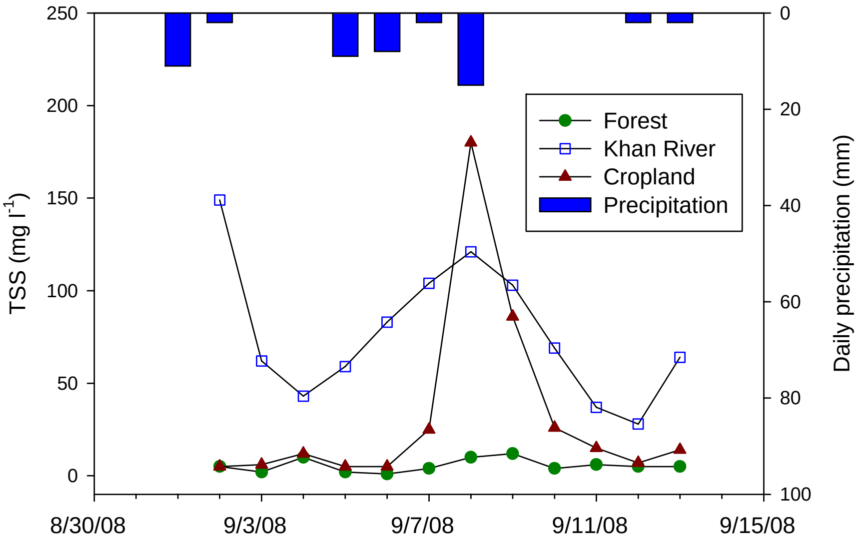

Fig. 3.4.6. Daily changes in precipitation and the concentration of TSS (mg l^{-1}) in the forest (Pa) and agricultural (Mout) streams and Khan River.

Summary and implications

Two main implications from the results can be summarized as follows:
Monsoon rainfalls exert a strong control on the terrestrial export of sediments and dissolved organic matter, with stronger responses in deforested and/or steep mountainous watersheds.
Rapid increases in suspended sediment in response to intense rainfall events can account for often missing but substantial portions of annual terrestrial export of C and metals associated with different sediment size fractions.

Overall our results suggest that flashy responses of watershed export of sediments and metals to intense and extreme rainfalls can pose a threat to surface water quality in mountainous watersheds, with climate impacts amplified by watershed topographic features and land use change. These results can be used as baseline information that is essential in assessing and managing risks associated with water quality in mountain watersheds from climate change and weather extremes.

3.5. Climate risk assessment and management – synthesis of field monitoring data and the second workshop results

Climate risk identification through statistical analysis

Identification and effective management of different levels of risks represent a core effort of sound management of water resources. Risk and other associated terms are here defined based on WHO Guideline for Drinking-water Quality (WHO, 2008), as delineated below. In assessing ‘climate risks’ to water quality, we will deal primarily with water contaminants as ‘chemical hazards’ and the likelihood of realization of identified hazards.

- A hazard is a biological, chemical, physical or radiological agent that has the potential to cause harm;
- A hazardous event is an incident or situation that can lead to the presence of a hazard; and
- Risk is the likelihood of identified hazards causing harm in exposed populations in a specified time frame, including the magnitude of that harm and/or the consequences.

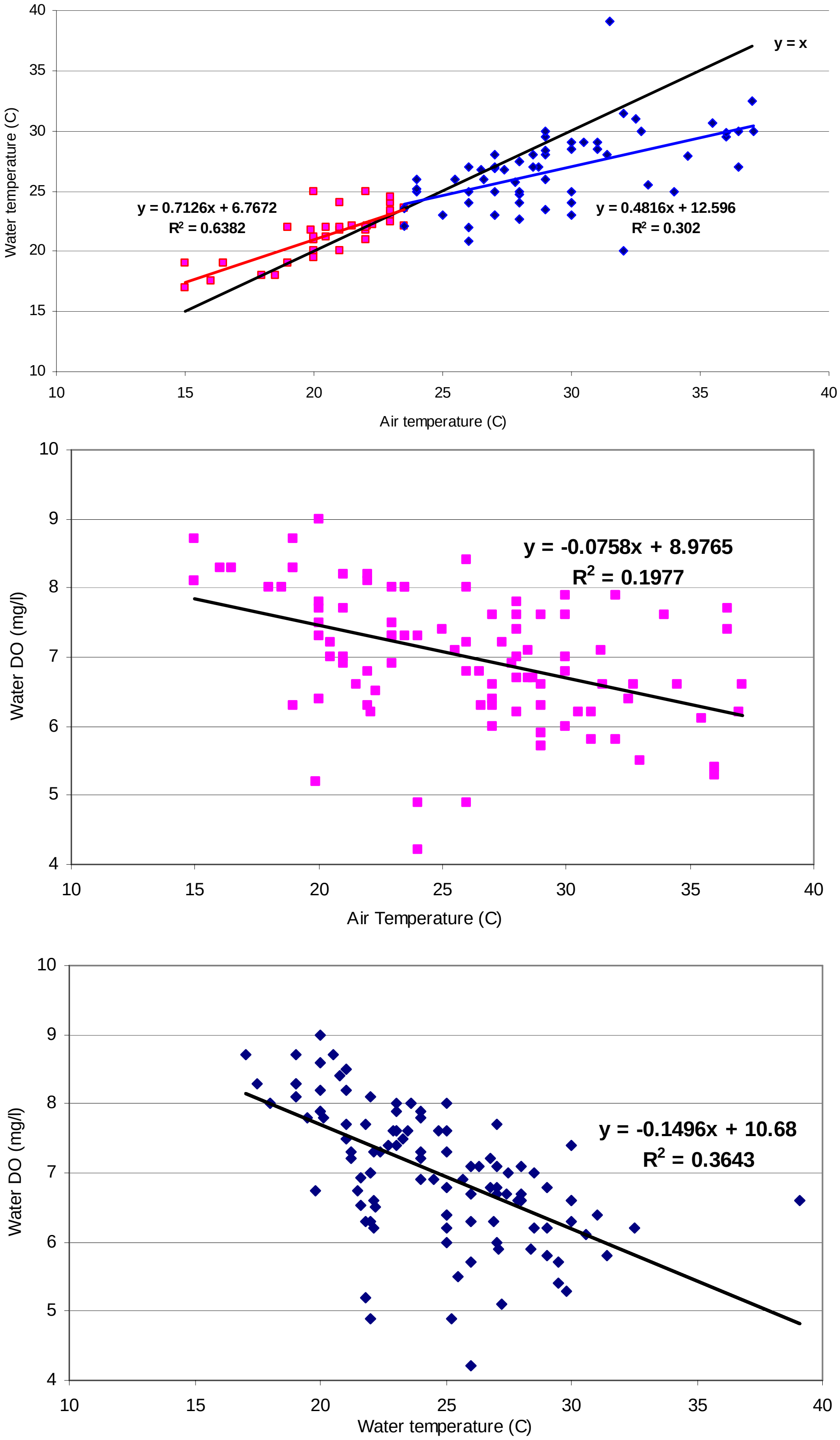

Fig. 3.5.1. The relationships between air and water temperatures (a), impact of air temperature (b) and water temperature (c) on dissolved oxygen (DO) in the Kok River, Chiang Rai, 1999-2008 (Source: Syers et al., 2009)

Both the project monitoring results and long-term data from local sources have displayed parameter-specific relationships with either temperature or precipitation. Water quality parameters that were assessed to have weak to significant relationships with air temperature include water temperature, DO, BOD and COD (Sarjiya et al., 2009; Syers et al., 2009). Using 10-year monitoring data collected at four stations along the Kok River flowing through Chiang Rai Province, Northern Thailand, Syers et al. (2009) showed a positive correlation between air and water temperatures (Fig. 3.5.1a). Both air and water temperatures had significantly negative relationships with DO, although the correlation was much stronger for the relationships between water temperature and DO (Fig. 3.5.1b & c). Similar negative relationship between water temperature and DO was found in the Brantas River, Indonesia (Sarjiya et al., 2009), although no clear temperature effect was found in another Thai case study presented during the second workshop (Wirojanagud et al., 2009). Contrasting findings again point to the concurrent influences of land use change and ensuing changes in water pollution.

Although it is very difficult to distinguish climate effects from other concurrent influences on water quality, site-specific empirical relationships between temperature and DO well illustrate warming-induced risks to surface water quality. Since more frequent occurrences of above-average or extreme hot days have been observed along with long-term trends of warming across East Asia (Cruz et al., 2007; Choi et al., 2009), reductions in DO at higher air and water temperatures could have significant implications for water quality management, particularly in subtropical and tropical regions. In the case of Chiang Rai, relatively low levels of DO almost down to 5 mg L^{-1} were observed at air temperatures higher than 30^{o}C, suggesting that decreased saturation of DO in warmer water might occur more frequently in response to climatic warming, increasing the likelihood of anoxia in very polluted freshwater systems. Warmer temperature can also increase organic matter decomposition, elevating BOD. Given the longer residence time and minimal rainfall dilution of organic pollutants during the dry season, temperature-related water quality risks can be substantially elevated during long, severe droughts.

Hydroclimatic parameters generally showed stronger relationships with many water quality parameters than temperature. These relationships can basically fall into two categories. First, positive relationships were found between precipitation or discharge and water quality parameters such as SS and its associated metals, dissolved organic matter, and some of nutrients (N and P). In contrast, chemicals that have relatively high ‘soluble transport index’, or the tendency to be present in the soluble form (Meybeck et al., 1996) usually showed negative relationships with hydroclimatic parameters. These chemicals include alkali and earth alkaline metals, Cl, and SO_4^{2-}. In the latter case, increased water flow during each storm event or the whole rainy season appeared to result in dilution of readily soluble chemicals without much additional runoff inputs to the water body. The dilution effect of increased water flow was also manifested by significantly lower conductivity during the monsoon compared to the dry periods in both biannual and intensive monitoring.

Results from the first-year biannual monitoring showed clear seasonality in many of measured water quality parameters and monsoon rainfalls appeared to play a crucial role for this seasonality, as presented in the section 3.3. To assess risks of water quality deterioration, the rainfall-related seasonality should be further examined with data from long-term monitoring or intensive event sampling. During the second workshop, Hahn et al. (2009) presented the results from their statistical analyses using MRC WQMN data collected from 1985 to 2004 at different locations along the LMR. They showed that temporal variations in some of analyzed parameters, including SS, alkalinity and conductivity could be well explained by either precipitation and river flow alone or combined. These results, along with other analyses available from the literature (e.g., MRC, 2007), suggest variations in SS as a key factor in determining the magnitude of water quality risks posed by variability and extremes in monsoon rainfalls across many steep terrains of East Asia. While SS itself is a threat to both aquatic organisms and human health, its capacity to carry other contaminants represents a challenge in determining general water quality risks involving both and many related risk factors. Therefore, our results suggest that parameter-specific risk assessment rather than quantifying integrated risk index would be more realistic. For instance, the relationships between TSS and metals presented in the previous section (Fig. 3.3.3) could be used in assessing risks of metal contamination after estimating expected increases in SS in response to an extreme event using regression between SS and hydroclimatic parameters.

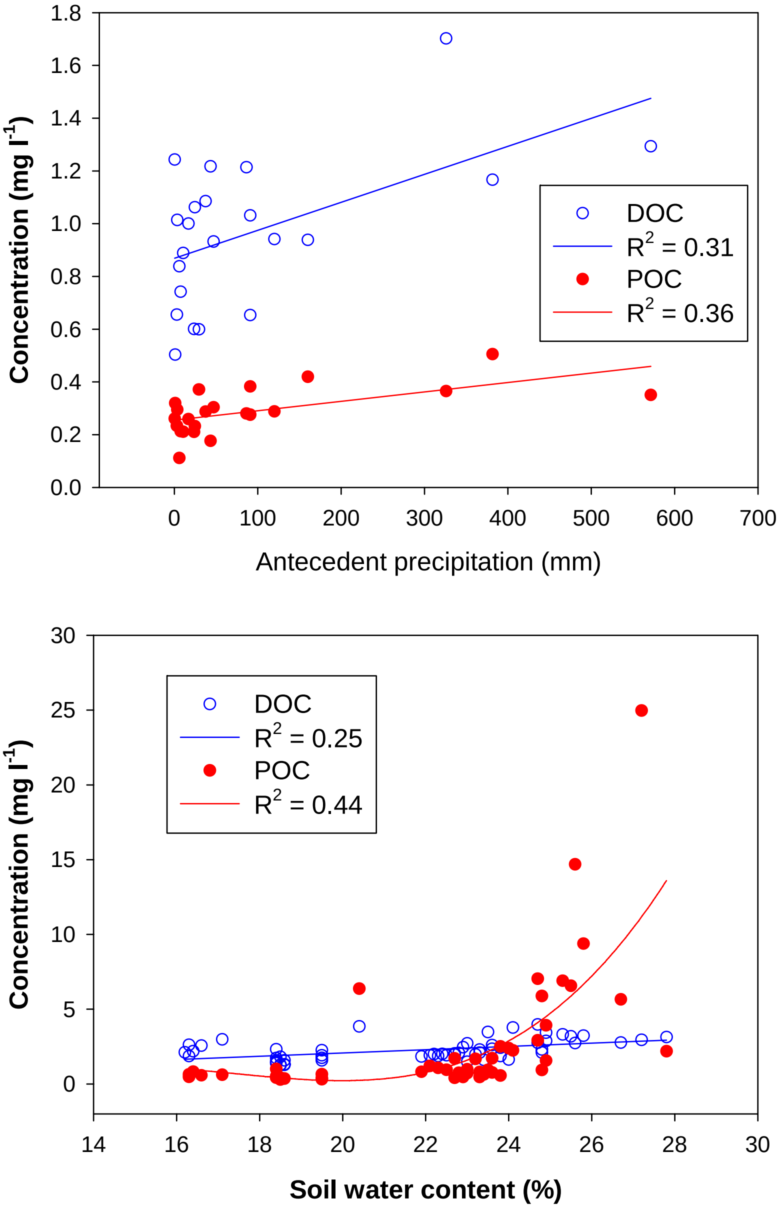

Fig. 3.5.2. The relationships between hydroclimatic conditions (a. antecedent precipitation; b. soil water content) and the concentrations of DOC and POC at a forest stream in the intensive monitoring site in Korea. The lines through the plots are best-fit regression lines with all R2 statistically significant at $P < 0.05$. (Source: Park et al. unpublished data).

Another reliable approach in identifying climate risks, particularly those associated with extreme climate events, would be examining short-term variations in specific water quality parameter and deviations out of the threshold values during a storm event. At the intensive monitoring site in Korea, short-term temporal changes at a forest stream were investigated during several monsoon rainfall events using a very intensive sampling scheme, as presented in the section 3.4. Fig. 3.5.2 presents an illustrative example emphasizing short-term, flashy responses of sediments eroded from the steep mountain hillslopes and attached C. Compared to the relationships between the concentrations of DOC and POC and antecedent precipitation over the two weeks before regular sampling (Fig. 3.5.2a), which showed weaker responses of POC to hydroclimatic variations, POC concentrations increased non-linearly and exceeded those of DOC at above certain threshold values of hydrologic conditions (soil water content in this case) during an extreme rainfall event with total precipitation over 400 mm for three days (Fig. 3.5.2b). This result suggests that risks of water quality can occur very quickly and transiently in response to extreme rainfall events. As shown in the previous section, the concentrations of some hazardous metals associated with eroded sediments can also rise up to very high levels (Fig. 3.4.3), posing a potential hazard to the downstream aquatic ecosystems and human health if the water is used as a drinking water source.

Climate risk prediction based on empirical relationships and incorporation into risk management system

Water quality is determined by complex interactions and feedbacks among numerous physical, chemical and biological parameters of the water body as well as watershed characteristics. This alone represents an adequate rationale for parameter-specific risk assessment. Based on parameter-specific relationships, empirical prediction models can be built. Using these models changes in certain water quality parameters under specific climate change scenarios can be estimated without employing complex mathematical models (Fig. 3.5.3). Considering that even very advanced water quality models cannot be applied to an integrative assessment of multi-parameter water quality deterioration, we suggest the use of empirical relationships between hydroclimates and water quality parameters, for which long-term monitoring data are available from local sources. Estimated changes in specific water quality parameters in response to predicted changes in climatic factors of interest could be evaluated against water quality standards or guidelines prepared by international or national water authorities.

Basic components of a risk management system include not only identification and assessment of a risk but also prediction of risk levels and associated ecological, societal and economic losses under feasible scenarios driven by major risk factors (Fig. 3.5.3). Since predicting expected losses from a climate risk is beyond the scope of this study, the project has focused on working out conceptual and methodological frameworks for the prediction of climate risks to water quality. Developing more complete climate risk management systems would require more interdisciplinary approaches including risk assessment using risk index and application of social science approaches in assessing scio-economic losses in water resources incurred from disastrous climate events.

A good example of climate risk index is ‘Global Climate Risk Index’ developed by Germanwatch. The Germanwatch Climate Risk Index (CRI) identifies countries affected by extreme weather events in specific time periods, usually annually, based on four indicators, including total number of deaths, deaths per 100,000 inhabitants, absolute losses in million US$ purchasing power parties and losses per unit GDP in % (Harmeling, 2007). The CRI is presented as the average rank of each country in the four indicators analyzed.

Simplified, general risk index such as CRI can be modified to water sector after further refining the approach by quantifying ecological or scio-economic losses expected from hazardous weather events. Webby et al. (2007), for example, applied the concept of ‘conditional value at risk’ as a coherent measure of expected loss given that actual loss exceeds some value at risk threshold in assessing quantitatively the risk of macro-economic damage to the fishery resources of the Tonle Sap Lake in Cambodia in response to reduced flow of the LMR during the flood season. Similar approaches will contribute to a more accurate assessment of climate risks to water quality accompanying various hazardous climate events. Efficient systems for climate risk management can build on a scientific assessment and prediction of risk levels and expected losses.

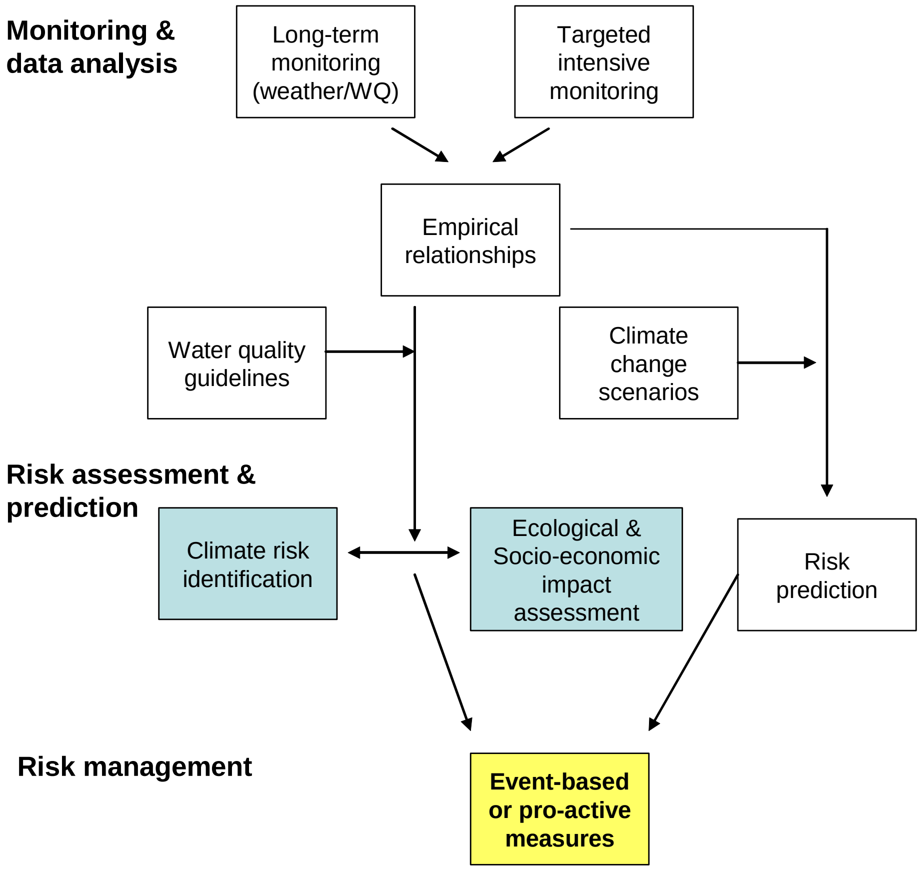

Fig. 3.5.3. Conceptual framework for developing a water quality-focused climate risk assessment and management system

4.0 Conclusions

Comprehensive literature reviews done as part of Project Module 1 have identified complex relationships between climate and surface water quality in East Asia. While clear warming trends have been observed over the recent decades across East Asia, recent changes in precipitation amount and intensity showed no uniform trends. However, increasing variability and extremes in precipitation have been observed across many parts of East Asia. In northern latitudes winter snowpack dynamics and soil freeze/thaw cycles will play a pivotal role in the release of acids and nutrients from steep hillslopes, with soil and surface water acidification buffered by soils rich in base cations. In mid latitudes including the Korean Peninsula and some parts of China, increasing amount and intensity of summer monsoon rainfalls, in combination with land use change and steep topography will continue to contribute to water quality deterioration by increased sediments and nutrients in the downstream rivers and reservoirs. In many parts of the southern China, lower precipitation with large year-to-year variations have been observed in recent years. This variability in precipitation appears to have had a substantial influence on year-to-year variations in acidity and nutrient fluxes in forest soils and headwater streams under increasing levels of acid deposition.

Compared to Northeast Asia, patterns of recent climate change in Southeast Asia have been more complex and subtle, without displaying clear increases in either precipitation amount or extreme events. Lack of long-term quality monitoring data represents another challenge in establishing the linkages between climate and water quality. Despite these limitations, our review identified parameter-specific water quality responses to recent or future climate changes, including decreases in DO saturation during hot and dry periods and a very strong control of hydroclimates on SS. Effects of large dams newly constructed in China upstream of the LMR and rapid land use change within the LMR basin have been suggested to play a key role in determining the magnitude of changes in SS and associated contaminants in response to ongoing and future changes in monsoon rainfall regimes.

The results from the pilot study in 2006 and 2-year monitoring done as the Project Module 2 activity added new insights into spatial patterns of water pollution and potential climate change impacts on surface water quality in eight different East Asian countries. Contrasting seasonal patterns of different water quality parameters suggest that increased rainfalls during wet season can increase terrestrial inputs of suspended sediments and dissolved organic matter from various non-point sources, while increased streamflow can lead to in-stream dilution of some chemicals having limited inputs via surface runoff. Increased suspended sediments during wet period coincided with increases in concentrations of some of measured metals (Al, Co, Fe, and Pb), suggesting an important role of suspended sediments in determining the fate and speciation of metals in surface waters. Comparison of seasonal patterns suggest vulnerability of water quality in watersheds undergoing rapid land use change, especially in wetter years.

The results from the intensive monitoring conducted at two selected watersheds as part of the second-year field monitoring emphasized that monsoon rainfalls could exert a strong control on the terrestrial export of sediments and dissolved organic matter, with stronger responses in deforested and/or steep mountainous watersheds. Flashy responses of watershed export of sediments and associated contaminants (e.g., toxic metals) to intense and extreme rainfalls can pose a threat to surface water quality in vulnerable areas such as steep mountainous watersheds, with climate impacts often amplified by land use change.

To develop a scientific risk management system identification and assessment of climate risks should be accompanied by prediction of site- and water quality parameter-specific climate risks based on empirical relationships established by analyzing long-term climate and water quality data from local sources. In addition, a more through evaluation is required to assess ecological, societal and economic losses expected under various climate change scenarios. Therefore, developing more complete climate risk management systems would require more interdisciplinary approaches including risk assessment using risk index and application of social science approaches in assessing scio-economic losses in water resources by disastrous climate events.

In sum, our results suggest that climate change, changes in monsoon rainfall regimes in particular, can affect surface water quality in East Asia, but the magnitudes of environmental and socio-economic impacts would depend on the vulnerability of impacted areas and water quality parameters considered. Land use change in steep terrains and water flow diversion through dam construction will play a crucial role in determining the magnitudes of watershed responses to climate change. Spatially extensive monitoring complemented with more detailed study of short-term water quality changes will provide scientific baseline information in assessing risks of water quality deterioration associated with climate change and variability. Efficient systems of climate risk management can build on this scientific assessment and prediction of site- and parameter-specific risks and associated ecological and socio-economic losses.

5.0 Future Directions

The primary objective of the project was to build a regional collaborative research network linking individual research efforts focused on climate change impacts in water sector at the local scale. The workshops and on-site collaboration have contributed to connecting otherwise scattered research efforts into a researcher network covering most of East Asian regions. Maintaining this collaboration network on a long-term basis would require further research activities, including follow-up research projects at national or international scales, researcher exchange and capacity building of next-generation scientists.

The lack of long-term monitoring data has been suggested as the major challenge in identifying and assessing climate risks. Information dissemination will facilitate increased access and utilization of existing long-term data such as data bases maintained by MRC. On the other hand more rigorous efforts should be paid to initiate or expand national water quality monitoring programs benchmarking model programs in European and North American countries. The project results highlighted site- and season-specific patterns of water quality response to climate variability and extremes. While changes in winter snow regimes were suggested as a primary factor for water quality in headwater streams in Northern Japan, higher summer temperatures were proposed as a key factor in determining water quality deterioration during extended droughts in tropical watersheds of Southeast Asia. Given the variety of spatial and climatic differences in East Asia, future study of climate change impacts on water quality needs to invest more research efforts to site-specific response patterns.

Two-year research efforts could not accomplish all project goals. Above all, the goal and research questions of the Project Module 3 were inadequately addressed. Since climate risk management consists not only of scientific assessment of identified climate risks but also of evaluation of expected ecological and socio-economic losses, developing full-fledged risk management systems require more interdisciplinary approaches. Through future collaboration activities also involving social scientists, more research efforts will be given to the translation of scientific data into practical information for sound management of climate risks to surface water quality in a changing climate.

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Appendix

Conferences/Symposia/Workshops

1. The First Scoping Workshop in Kangwon National University, Chuncheon, Korea

- Program

Project Member Meeting October 7, Sunday

15:00 ~ 17:00	Ji-Hyung Park / Kangwon National Univeristy, Korea Discussion for Future Project Activities
17:00 ~ 18:00	Edu Inam / Gwangju Institute of Science and Technology, Korea Collecting and Processing Water Samples for Water Quality Assessment

Opening & Introduction October 8, Monday

10:00 ~ 11:00	President, Kangwon National University Welcome Address Kyoung-Woong Kim/ Gwangju Institute of Science and Technology, Korea Welcome Speech and Introduction of UNU & GIST Joint Programme on Science and Technology for Sustainability Ji-Hyung Park / Kangwon National Univeristy, Korea Regional Collaborative Research on Climate Change Impacts on Surface Water Quality in Eastern Monsoon Asia towards Sound Management of Climate Risks – Overview of the Project and the 1st Workshop

Invited Speeches

Session I. Climate Change Impacts on Northeast Asian Watersheds

Chair: Ji-Hyung Park

11:20 ~ 12:00	Myron J. Mitchell / Sunny-College of Env. Sci. & Forestry, USA (Keynote Speech) Climate Change in Temperate Forest Ecosystem with Special Reference to Eastern Asia and Northeastern United States
13:39 ~ 14:00	Hideaki Shibata / Hokkaido University, Japan The Spatial and Temporal Patterns of Surface Water Chemistry in Forest Watersheds in Hokkaido
14:00 ~ 14:30	Bomchul Kim / Kangwon National University, Korea Storm Runoffs from a Rural Watershed and the Limnological Effects on a Reservoir, Lake Soyang, Korea
14:30 ~ 15:00	Hojeong Kang / Yonsei University, Korea Effects of Water level Drawdown on Microbial Processes in Wetlands

Session II Climate Change Impacts on Southeast Asian Watersheds

Chair: Suthipong Sthiannopkao

15:20 ~ 16:00	Mariza Costa-Cabral / University of Washington, USA Net Ecosystem Production of the Lower Mekong River: Connectivity of Upstream Processes to the South China Sea with Changes in Climate, Streamflow, Regulation and Landuse
16:00 ~ 16:30	Xi Xi Lu / National University of Singapore, Singapore

	Sediments Flux Changes in the Mekong River Basin: Impact of Human Activities and Climate Change
16:30 ~ 17:00	Khoi Tranminh / Mekong River Commission, Lao PDR Monitoring and Assessment of Water Quality in the Lower Mekong River
17:00 ~ 17:30	Sunbeak Bang / Gwangju Institute of Science and Technology, Korea Seasonal Variation of Arsenic Concentration in Groundwater of Vietnam

Project Member Presentations October 9, Tuesday

Chair: Edu Inam

8:30 ~ 8:50	Suthipong Sthiannopkao / Gwanju Institute of Science and Technology, Korea The Relationship of Climate and Hydrological Parameters to Surface Water Quality in the Lower Mekong River
8:50 ~ 9:10	Lei Duan / Tsinghua University, China Monitoring Surface Water and Soil Water Quality in Small Forested Catchments in China
9:10 ~ 9:30	John Keith Syers / Mea Fah Luang University, Thailand Impact of Climate Change on Water Quality in Northern Thailand: Research Needs and Opportunities
9:30 ~ 9:50	Wanpen Wirojanagud / Khon Kean University, Thailand Impact of Ambient Temperature Change on Water Quality: Case Study of the Phong River, Northeast Thailand
	Break
10:10 ~ 10:30	Vibol Sao / Royal University of Agriculture, Cambodia Potential Impacts of Climate Change on Surface Water Quality in Cambodia
10:30 ~ 10:50	Nguyen My Hoa / Cantho University, Vietnam Surface Water Quality in Dry and Rainy Season in Long Auyen Acid Sulphate Soils Quadrangle in Mekong Delta, Vietnam
10:50 ~ 11:10	Quoc Tinh Huynh / Cantho University, Vietnam Effects of Waste Water from Tra Noc Industrial Zone on Adjacent Rivers in Can Tho City
11:10 ~ 11:30	Mohd Harun Abdullah / University of Malaysia Sabah, Malaysia Water Chemistry in Downstream Region of Tuaran River: A Preliminary Assessment on Seawater Intrusion due to Sea Level Rise
11:30 ~ 11:50	Dwi Agustiyani / Indonesian Institute of Sciences, Indonesia Climate Change Impact on Water Quality in Citarum River, West Java, Indonesia

- Participants list

- INVITED SPEAKERS

JAPAN

Dr. Hideaki Shibata	Professor Field Science Centre for Northern Biosphere Hokkaido University, Japan shiba@fsc.hokudai.ac.kr

KOREA

Dr. Bomchul Kim	Professor Department of Environmental Sciences Kangwon National University, Korea bkim@kangwon.ac.kr
Dr. Sunbaek Bang	Research Assistant Professor International Environmental Research centre, Gwangju Institute of Science and Technology (GIST), Korea sbang@gist.ac.kr
Dr. Hojeong Kang	Professor Department of Civil and Environmental Engineering Yonsei University, Korea hj_kang@yonsei.ac.kr

LAO PDR

Dr. Khoi Tran Minh	Research Officer Environmental Dovision Mekong River Commission, Lao PDR khoi@mrcmekong.org

SINGAPORE

Dr. Xi Xi Lu	Professor Department of Geography National University of Singapore, Singapore geoluxx@nus.edu.sg

USA

Dr. Myron J. Mitchell	Distinguished Professor College of Environmental Science & Forestry, State University of New York, USA mitchell@mailbox.syr.edu
Dr. Jeffrey E. Richey	Professor School of Oceanography University of Washington, USA jrichey@u.washington.edu

- PROJECT MEMBERS

CAMBODIA

Vibol Sao	Lecturer Faculty of Agricultural Technology and Management Royal University of Agriculture, Cambodia saovibol@yahoo.com

CHINA

Lei Duan	Professor Department of Environmental Science and Engineering Tsinghua University, China iduan@tsinghua.edu.cn

INDONESIA

Dwi Agustiyani	Researcher

Research Centre for Biology
Indonesian Institute of Sciences, Indonesia
titinagustin@yahoo.com

KOREA

Ji-Hyung Park
Project Leader
Professor
College of Forest & Environmental Science
Kangwon National University, Korea
jihyungpark@kangwon.ac.kr

Kyoung-Woong Kim
Project Co-PI
Professor & Director
International Environmental Research Centre
Gwangju Institute of Science and Technology, Korea
kwkim@gist.ac.kr

Suthipong Sthiannopkao
Research Assistant Professor
International Environmental Research Centre
Gwangju Institute of Science and Technology, Korea
suthi@gist.ac.kr

Edu Inam
Programme Officer
International Environmental Research Centre
Gwangju Institute of Science and Technology, Korea
edu@gist.ac.kr

MALAYSIA

Mohd Harun Abdullah
Professor
School of Science and Technology
University of Malaysia Sabah, Malaysia
harunabd@ums.edu.my

THAILAND

Wanpen Wirojanagud
Professor
Research Centre for Envrion. & Hazardous Waste Mgt.
Khon Kaen University, Thailand
wanpen@kku.ac.th

John Keith Syers
Professor
Mae Fah Luang University, Thailand
keith@mfu.ac.th

VIETNAM

Nguyen My Hoa
Senior Lecturer
Soil Science & Land Management Department
Cantho University, Vietnam
nmhoa@ctu.edu.vn

2. The Second Synthesis Workshop at Universiti Malaysia Sabah, Kota Kinabalu, Malaysia

- Program

Opening & Introduction	February 18, Wednesday
10:00 ~ 12:00	Vice Chancellor, Universiti Malaysia Sabah Welcome Address
	Linda Anne Stevenson / Asia-Pacific Network for Global Change Research (APN) Welcome Speech
	Kyoung-Woong Kim / Gwangju Institute of Science and Technology, Korea Welcome Speech and Introduction of UNU & GIST Joint Programme on Science and Technology for Sustainability
	Ji-Hyung Park / Kangwon National University, Korea Regional Collaborative Research on Climate Change Impacts on Surface Water Quality in Eastern Monsoon Asia towards Sound Management of Climate Risks – Overview of the Project Activities

Session I. Regional Comparison

13:30 ~14:00	Edu Inam / International Environmental Research Centre, Korea
14.00 ~15.00	Ji-Hyung Park / Kangwon National University, Korea
15.00 ~15.30	Suthipong Sthiannopkao / Gwangju Institute of Science and Technology, Korea

Session II. National trends

15:30 ~16:00	Lei Duan / Tsinghua University, China
16:00 ~16.30	John Keith Syers / Mea Fah Luang University, Thailand
16.30 ~17.00	Wanpen Wirojanagud / Khon Kean University, Thailand
!7:00 ~17:30	Sianouvong Savathvong, Souphanouvong University / Lao PDR

Session III. National Trends	February 19th, Thursday
10:00 ~ 10:30	Vibol Sao / Royal University of Agriculture, Cambodia
10:30 ~ 11:00	Nguyen My Hoa / Cantho University, Vietnam
11:00 ~ 11:30	Mohd Harun Abdullah / Universiti Malaysia Sabah, Malaysia
11:30 ~ 12:00	Antonius Sariyiya / Indonesian Institute of Sciences Indonesia

Session IV. Open Session

13.30~14.00 Mohd Kamil / Universiti Malaysia Sabah, Malaysia

- Participants list

CAMBODIA

Vibol Sao	Lecturer Faculty of Agricultural Technology and Management Royal University of Agriculture, Cambodia saovibol@yahoo.com

CHINA

Lei Duan	Professor Department of Environmental Science and Engineering Tsinghua University, China iduan@tsinghua.edu.cn

INDONESIA

Antonius Sarjiya	Researcher Research Centre for Biology Indonesian Institute of Sciences, Indonesia antyuni@yahoo.com

KOREA

Ji-Hyung Park	Project Leader Professor College of Forest & Environmental Science Kangwon National University, Korea jihyungpark@kangwon.ac.kr
Kyoung-Woong Kim	Project Co-PI Professor & Former Director International Environmental Research Centre Gwangju Institute of Science and Technology, Korea kwkim@gist.ac.kr
Suthipong Sthiannopkao	Research Assistant Professor International Environmental Research Centre Gwangju Institute of Science and Technology, Korea suthi@gist.ac.kr
Edu Inam	Research Fellow International Environmental Research Centre Gwangju Institute of Science and Technology, Korea edu@gist.ac.k

LAOS PDR

Sianouvong Savathvong	Professor Souphanouvong University, Lao PDR sianouv@yahoo.com

MALAYSIA

Mohd Harun Abdullah	Professor School of Science and Technology

	Universiti Malaysia Sabah, Malaysia harunabd@ums.edu.my
Mohd Kamil Yusoff	Professor Faculty of Environmental Studies Universiti Putra Malaysia mkamil@env.upm.edu.my

THAILAND

Wanpen Wirojanagud	Professor Research Centre for Envrion. & Hazardous Waste Mgt. Khon Kaen University, Thailand wanpen@kku.ac.th
John Keith Syers	Professor Mae Fah Luang University, Thailand keith@mfu.ac.th

VIETNAM

Nguyen My Hoa	Professor Soil Science & Land Management Department Cantho University, Vietnam nmhoa@ctu.edu.vn

Funding sources outside the APN

- International Environmental Research Center at Gwangju Institute of Science & Technology Korea provided in-kind support in the form of chemical analysis and internship training (15,000 US$ for the first year and 10,000 US$ for the second year) via funding from Ministry of Education, Science & Technology of Korea as well as administrative support as the organizer of both workshops.

- Co-funding was provided by the Korea Research Foundation Grant funded by the Korean Government (KRF-2007-313-F0033) for the intensive monitoring in Korea during the second-year term.

- Institute of Forest Science at Kangwon National University, Korea supported the first workshop as a co-organizer.

- The Universiti Malaysia Sabah, Kota Kinabalu, Malaysia supported the second workshop as a co-organizer.

Glossary of Terms

APN: Asia-Pacific Network for Global Change Research
BOD: biological oxygen demand
COD: chemical oxygen demand
DO: dissolved oxygen
DOC: dissolved organic carbon
IERC: International Environmental Research Center
IPCC: Intergovernmental Panel on Climate Change
LMR: Lower Mekong River
LSW: Lake Soyang Watershed
MRC: Mekong River Commission
POC: particulate organic carbon
SEA START RC: Southeast Asia START Regional Center
SS: suspended solid
TIN: total inorganic nitrogen
TN: total nitrogen
TP: total phosphorus
TSS: total suspended solid
UVA: ultraviolet absorbance
UVA_{254}: UVA at 254 nm
WQMN: Water Quality Monitoring Network (of MRC)