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Acronyms

COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
EHM	Ecological Health Monitoring
EP	Environment Programme
ISO	International Organization for Standardization
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NMCs	National Mekong Committees
PWQ	Procedures for Water Quality
QA/QC	Quality Assurance/Quality Control
TSS	Total Suspended Solids
WQCA	MRC Water Quality Criteria for the Protection of Aquatic Life
WQCH	MRC Water Quality Criteria for the Protection of Human Health
WQI	Water Quality Index
WQIag	Water Quality Index for Agricultural Use
WQIal	Water Quality Index for the Protection of Aquatic Life
WQIhi	Water Quality Index for Human Impacts
WQMN	Water Quality Monitoring Network

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

In 2011 MRC conducted a multi-media monitoring and assessment program (MMMAP) to assess levels of persistent micro-pollutants in water, sediment and biota in the Lower Mekong Basin (LMB). The long-term objectives of this program were to: (i) describe the status of ambient environmental quality in the LMB; (ii) provide a baseline for detecting trends of persitstent micro-pollutants in the environment over time; and (iii) better discern changes in environmental quality due to point and non-point contaminant sources to the Mekong River mainstream and its major tributaries.

A total of 28 stations were included in the MMMAP 2011 field survey; 25 of these stations are regularly monitored under the MRC water quality monitoring programme; 3 additional stations were monitored downstream of potential contaminant sources.

At each station, water and sediment samples were collected from mid-May to June. Also biota (fish or/and molluscs) samples were collected from 20 stations between March and May. Samples were analysed for basic water quality parameters (temperature, pH, conductivity, salinity, chlorophyll, oxygen, BOD, COD, suspended solids, oil & grease), nutrients (N, P), heavy metals (Hg, Cd, Pb, As, Cr, Ni, Cu) and organic toxic substances (DDT, PCB, HCB, Endrin, Endosulfan, Heptachlore, HCH, CHL, phenols and CN)

The results showed that the Mekong River mainstream surface water has a higher conductivity compared to tributaries (229.1 ± 39.8 and 124.0 ± 59.1 μmhos/cm, respectively). The pH is fairly stable throughout the river, with an average value of about 7.2. The water temperature gradually increases from 24°C, at the LMB headwater, to some 30 °C in the Mekong Delta. The upper reaches of the lower Mekong River tend to have higher levels of suspended solids and dissolved oxygen than downstream sections. Most stations had dissolved oxygen and BOD levels that were higher than the MRC's criteria and target values for the protection of aquatic life (WQCA) and human health (WQCH). COD levels at all stations exceeded MRC's criteria and target values for the protection of human health, and were high compared to the levels found in MRC water quality monitoring programme. The oil and grease (O&G) levels found in Mekong River were mostly low, but a few stations close to urban centres, had slightly elevated levels, such as the Phnom Penh Port, Luang Prabang and Vientiane. Chlorophyll values tended to be higher in the tributaries, which indicate more eutrophic conditions than in the mainstream.

Total dissolved nitrogen (TDN) concentrations were similar in both the Mekong mainstream and tributaries, whereas total dissolved phosphorus (TDP) concentrations were slightly lower in the tributaries, with the exception of the Tonle Sap region, as compared to the mainstream. Elevated levels of total dissolved nutrients at the Houa Khong station indicate an inflow of nutrients from the upper Mekong River in China. Somewhat elevated nutrient levels were also found in downstream sections such as Tonle Sap and the Mekong Delta.

Among the toxic pollutants measured, mercury (Hg) and lead (Pb) are those of highest concern. Although mercury levels in water generally were low, sediment mercury levels at many stations exceeded the ANZECC upland sediment quality criteria. Mercury was also the only heavy metal that was found in much higher levels in fish as compared to sediments, indicating biomagnification of this metal. Mercury levels in fish should be monitored further in future studies, as this could be of concern for human health if levels increase. The results indicate that the mercury levels in the Mekong River are of anthropogenic origin and further studies are needed to identify potential sources.

All lead sediment values exceeded the lower ANZECC quality criteria of 50 mg/kg dry weight, and half exceeded the higher criteria of 220 mg/kg dry weight. Compared to other studies the lead levels in water were high. Similar to mercury, the lead levels seem to be of an anthropogenic origin and further studies are needed to identify potential sources and the distribution of lead in the Mekong River environment.

Concentrations of other heavy metals did not exceed the lower ANZECC quality criteria of 50 mg/kg, and seem to mainly originate from natural resources such as rock and soil in the LMB.

Except for phenol, no organic micro pollutants were detected in water, sediments and biota, and previous studies indicate that these substances manly occur in levels below the detection limits of the analytical methods used in this study. Although this indicates low levels of these substances in the environment, it also highlights the importance to apply more sensitive methods in future monitoring of these substances.

Most phenol values in water were low, but levels at the Chiang Sean Pier, Chiang Khong, Vientiane, Pakse and Phnom Penh Port exceeded the MRC WQCA and WQCH thresholds. Elevated values of phenol at these stations indicate possible leakage of petroleum products close to cities and navigation routes.

Most of the cyanide concentrations from stations in the mainstream and in the tributaries station were below the WQCH and WQCA thresholds, while the concentrations at a few stations located in the same catchment area (Kok River) in the upper part of the Mekong River exceeded the thresholds.

Overall it can be concluded the Mekong River and its tributaries are still fairly unpolluted. The water quality in Northeast Thailand, Tonle Sap, the Mekong Delta and northern Laos close to Thailand, seems to be more impacted than in other sections of the lower Mekong River, partly because of more intensive agriculture and higher population densities in these areas. Also urban areas such as Luang Prabang, Vientiane and Phnom Penh show trends of increasing levels of some contaminants indicating the importance to continue monitoring these pollutants close to urban centres. The water and sediment in tributaries tend to have higher contaminants levels than that of the mainstream. Due to lack of pollutant loadings on a catchment basis, indications of significant basin-wide trends of any parameters cannot be directly linked with contaminant loadings from agricultural, urban and industrial sources. The fact that lead and mercury levels seem to be of an anthropogenic origin is probably of highest concern among the different micro pollutants measured and should be considered in future monitoring activities.

1. INTRODUCTION

1. INTRODUCTION

Water quality is an important indicator of environmental health in the Mekong River, with impaired conditions potentially affecting aquatic resources, human health and livelihoods of the people living in the Lower Mekong Basin (LMB). Recognising the importance of maintaining acceptable water quality conditions in the basin, the Mekong River Commission (MRC), under the direction of riparian countries, in 1985 initiated the Water Quality Monitoring Network (WQMN). Since its establishment, the network has tracked water quality at more than 90 sampling stations in the Mekong mainstream, in major tributaries, and in the Mekong Delta.

Overall, environmental quality status in the LMB is reviewed in MRC's 2010 State of the Basin report. This report characterises water quality throughout the LMB as continuing to be generally good. In the Mekong mainstream and tributaries, water quality mostly continues to meet requirements for the protection of aquatic life, human health, and agricultural use, with no restrictions on usage. Some degradation of water quality is however evident related to urban and industrial development and agricultural production. Higher nitrogen and phosphorus concentrations in water have been measured in areas of the LMB subject to intensive agriculture and human population pressures, especially downstream of major cities such as Vientiane and Phnom Penh, in northeast Thailand, and in the Mekong Delta. Similarly, elevated heavy metal and organic contaminant concentrations have been detected in sediments and aquatic organisms sampled in areas subject to industrial development and heavy river vessel traffic.

Recognising the need to assess environmental quality status and track basin-wide trends on an on-going basis, the MRC has undertaken additional periodic diagnostic water quality monitoring to gather data on environmental contaminants not measured as part of the WQMN. Following an integrated monitoring program conducted in 2003–2004, a multi-media monitoring and assessment program (MMMAP) was completed during 2010-2011 to evaluate water quality, sediment and biota in the LMB. The long-term objectives of this program are to: (i) more accurately describe the status of ambient environmental quality in the LMB; (ii) provide an improved baseline for detecting trends over time; and (iii) better discern changes in environmental quality due to point source and diffuse contaminant discharges in to the Mekong River mainstream and major tributaries.

To achieve these long-term objectives, the MMMAP employed a multi-modal approach, involving an expansion in both the suite of variables that were monitored, and in the spatial coverage of monitoring. Specifically, the program encompasses: (i) Mekong mainstream monitoring, concentrating on persistent contaminants, and identification of point and non-point contaminant sources,

Table 1-1: Rationales for the Multi-Media (Water, Sediment, Biota) Monitoring and Assessment.

	Mainstream	Tributaries, Point and Non-point Sources	Special Studies
Why?	Determine current levels, distributions and effects of contaminants in the Mekong mainstream.	Determine ambient environmental quality in tributaries potentially affected by point and non-point contaminant sources.	Determine the current condition of selected sub-basin aquatic ecosystems
How?	Describe longitudinal distribution of major contaminants in water, sediment, bottom biota and fish in the mainstream.	Screen tributaries for possible contaminant loading and ambient environmental quality.	Analyse data for current status; correlations of stress, exposure and response.
What, Where?	Water, sediment, bottom biota, and fish from reaches within the mainstream. Choose sites by systematic random sampling, over entire length of the river.	Near-field zones exposed to contaminant discharges. Water and sediment from major tributaries prior to confluence with mainstream.	Representative stations on major tributaries within selected sub-basins.

with particular importance placed on urban and industrial discharges, stressors from agriculture, and tributary discharges; (ii) monitoring of major tributaries, considering both ambient water quality status, and tributaries as point sources of contaminants to the Mekong mainstream; and (iii) sub-basin specific monitoring to evaluate existing and potential threats, with a particular emphasis on the Sesan, Sre Pok, Sekong (3Ss) river system which is subject to increasingly intensive development, and the Tonle Sap. The MMMAP design rationale and approach are summarised below.

The 2011 MMMAP cycle particularly focused on measuring contaminant levels in the Mekong mainstream, major tributaries and selected sub-basins, and identifying stressors likely to have increased future importance to environmental quality in the LMB. Monitoring of Mekong mainstream and tributary sites during this initial MMMAP cycle is considered adequate to characterise changes in water quality caused by development along the river. Recommendations will be made based on the 2011 monitoring findings to expand the spatial coverage of the MMMAP to assess the importance of tributaries as point and non-point contaminant sources, and conduct follow up point and non-point source studies focusing on specific locations that are being affected by development activities.

2. METHODOLOGY FOR MONITORING AND DATA ASSESSMENT

2. METHODOLOGY FOR MONITORING AND DATA ASSESSMENT

Sampling design, protocols and methodology applied during the MMMAP 2011 monitoring cycle are summarised here. Justification is provided for the changes to monitoring program design, sampling and analytical protocols. The implications of such changes in terms of analytical results and overall investigative strength of the MMMAP are elaborated. Finally, water quality standards applied in interpreting the results are discussed.

2.1 MONITORING STATION SELECTION

A total of 28 stations were approved by MRC for inclusion in the MMMAP 2011 monitoring cycle. The locations and detailed information for each sampling station are summarised in Table 2-1 and Figure 2-1.

The terms 'existing' versus 'additional' stations refer to how stations were selected. The 25 existing stations are the stations of the MRC water quality monitoring and biomonitoring programmes along the Mekong mainstream. These existing stations help provide the description of spatial variation in conditions throughout the river. In contrast, the additional stations were suggested to monitor downstream of potential contaminant sources. These 3 additional stations allow a better understanding of worst case conditions but provide no perspective of the spatial extent of contaminant concentrations along the river.

- TSR (Mekong River, Sob Rouak, Thailand): TSR is located at Ban Sob Rouak on the Mekong River, roughly 200 km downstream from the first location. It was added because the Rouak River flows from Myanmar through Thailand before draining into the Mekong River. It is also the first major tributary river entering the Mekong River.

- TKR (Kok River, Chiang Sean, Thailand): TKR is located in the Kok River, a tributary of the Mekong River, in Chaing Saen and is approximately 1 km upstream of the Kok River confluence. It was added because the Kok River flows through the northern part of Thailand before entering Lao PDR. The construction of Chiang Sean Pier 2 on the bank of the Kok River mouth is located nearby.

- CSR (Sekong River, Stung Treng, Cambodia): The CSR site is located near the Sekong Bridge in the Sekong River, a tributary of the Mekong River in Stung Treng. This site receives water from the Sesan, Sekong and Sreprok rivers before draining into the Mekong.

Previously, the number of stations included in the MMMAP 2011 sampling cycle was recommended at 35 (outlined in the Sampling

Table 2-1: MMMAP Sampling station locations, rationale for inclusion in programme and matrices monitored.

Station No.	Station Name	Target River	Coordinates[1]	MMMAP Selection Rationale	Intended Sampling Matrices		
					Water/ sediment	Mollusc	Fish
1	Houa Khong (LMH)	Mekong	47Q 0723733 2383320	– Mekong mainstream status and trend site	✓		
2	Sob Rouak (TSR)	Mekong	47Q 0613099 2250114	– Mekong mainstream status and trend site – Mekong transitional status	✓	✓ (Bivalves/ Sampling by UAE)	✓ (Benthopelagic carnivorous fish, / Sampling by fisherman at the site)
3	Chiang Sean Pier 1 (TMC)	Mekong	47Q 0613910 2241290	– Mekong mainstream status and trend site	✓		
4	Kok River Mouth (TKR)	Kok	47Q 0617914 2237053	– Thai-tributary status and Mekong mainstream point source	✓	✓ (Snails/ Sampling by fisherman at the site)	✓ (Benthopelagic carnivorous fish, /Sampling by fisherman at the site)
5	Chiang Khong (TCK)	Mekong	47Q 0655020 2231248	– Mekong mainstream status and trend site	✓	✓ (Bivalves/ Sampling by UAE)	
6	Luang Prabang (LPB)	Mekong	48Q 0205743 2206230	– Mekong mainstream status and trend site	✓		✓ (Benthopelagic carnivorous fish, Benthopelagic omnivorous fish/ buying from local market)
7	Vientiane (LVT)	Mekong	48Q 0240784 1988874	– Thai-Tributary status and Mekong mainstream point source	✓		✓ (Benthopelagic carnivorous fish, Benthopelagic herbivorous fish/ buying from local market)
8	Nakhon Phanom (TNP)	Mekong	48Q 0477964 1924362	– Large tributary status – Special study	✓	✓ (Snails/ Buying from local market)	
9	Xe Bang Fai (LFB)	Xe Bang Fai	48Q 0498437 1888075	– Large tributary status – Special study	✓		✓ (Benthopelagic carnivorous fish, Benthopelagic herbivorous fish/ buying from local market)
10	Kong Chiam (TMM)	Mun	48P 0552854 1692378	– Cambodia-tributary status and Mekong mainstream point source	✓	✓ (Bivalves/ Sampling by UAE)	✓ (Benthopelagic omnivorous fish/ Buying from fisherman at the site)

[1] Denote: d/s: downstream
u/s: upstream

11	Pakse (LPS)	Mekong	48Q 0583847 1671225	– Mekong mainstream status and trend site	✓	✓ (Snails/ Buying from local market)	✓ (Benthopelagic carnivorous fish / Buying from local market)
12	Stung Treng (CMR)	Mekong	48P 0605366 1498778	– Cambodia-tributary status – Potential contaminant source to Tonle Sap lake – Additional special study needed to characterise lake water quality – Large system	✓		
13	Siem Pang (CKM)	Sekong	48P 650057 1561663	– Limited scale special study to characterise environmental quality conditions in Tonle Sap Lake – Large system special study	✓		
14	Andoung Meas (CSS)	Sesan	48P 0748937 1534392	– Cambodia-tributary status and mainstream point source – Site also assesses water quality discharging from the lake	✓		
15	Lumphat (CSP)	Sre Pok	48P 717377 1490855	– Mekong mainstream status and trend site	✓		
16	Sekong River Mouth (CSR)	Sekong	48P 0605283 1496933	– Mekong mainstream status and trend site	✓		✓ (Benthopelagic carnivorous fish, Benthopelagic omnivorous fish/ buying from fisherman at the site)
17	Kratie (CKT)	Mekong	48P 0610528 1380235	– Mekong mainstream status and trend site	✓		✓ (Benthopelagic carnivorous fish/ buying from local market)
18	Chroy Changvar (CCV)	Mekong	48P 493265 1280960	– Mekong mainstream status and trend site	✓		

19	Back Prea (CBP)	Stoeng Sangke	48P 326601 1471822	– Mekong mainstream status and trend site	✓	✓ (Snails/ buying from fisherman at the site)	✓ (Benthopelagic carnivorous fish, / buying from fisherman at the site)
20	Phnom Khrom (CCK)	Great Lake	48P 0371676 1469209	– Mekong mainstream status and trend site	✓		
21	Prek Kdam (CTU)	Tonle Sap	48P 478812 1305957	– Mekong mainstream status and trend site	✓	✓ (Bivalves/ buying from fisherman at the site)	
22	Phnom Penh Port (CPP)	Tonle Sap	48P 491795 12809808	– Mekong mainstream status and trend site	✓		✓ (Benthopelagic carnivorous fish, ,Benthopelagic herbivorous fish/ buying from fisherman at the site)
23	Neak Loung (CNL)	Mekong	48P 530202 1244500	– Mekong mainstream status and trend site – Mekong transitional status	✓	✓ (Snails/ buying from fisherman at the site)	✓ (Benthopelagic carnivorous fish, Benthopelagic omnivorous fish/ buying from fisherman at the site)
24	Koh Khel (CKL)	Bassac	48P 503051 1245614	– Mekong mainstream status and trend site	✓	✓ (Bivalves/ buying from fisherman at the site)	✓ (Benthopelagic carnivorous fish buying from fisherman at the site)
25	Chau Doc (VCD)	Bassac	48P 513419 1183859	– Thai-tributary status and Mekong mainstream point source	✓	✓ (Bivalves/ buying from local market)	✓ (Benthopelagic carnivorous fish, Benthopelagic omnivorous fish/ buying from local market)
26	Tan Chau (VTC)	Mekong	48P 527221 1193924	– Mekong mainstream status and trend site	✓	✓ (Bivalves/ buying from local market)	✓ (Benthopelagic carnivorous fish, / buying from local market and fisherman at the site)
27	Can Tho (VCT)	Bassac	48P 587504 111895	– Mekong mainstream status and trend site	✓		✓ (Benthopelagic carnivorous fish,/ buying from fisherman at the site)
28	My Thuan (VTR)	Mekong	48P 598405 1136177	– Mekong mainstream status and trend site	✓		✓ (Benthopelagic carnivorous fish,/ buying from fisherman at the site)

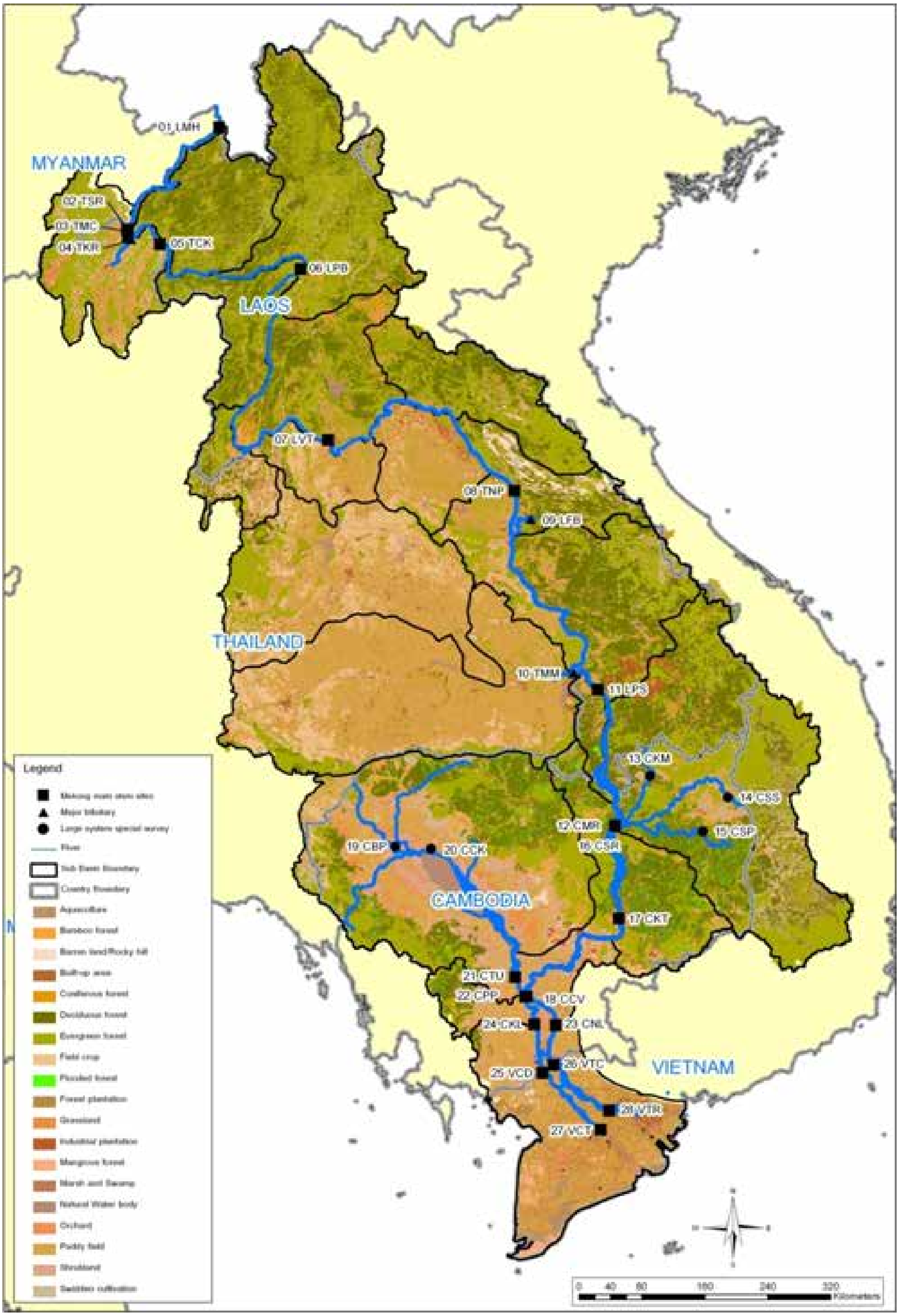


Figure 2-1: Location of monitoring stations in the Lower Mekong Basin

Design Report to 28 stations). Additional stations were proposed to strengthen the monitoring program through: (i) investigating major tributaries as contaminant sources; (ii) measuring water quality conditions immediately downstream of large urban centres; and (iii) examining trans-boundary water quality along the Mekong mainstream. The addition of sampling locations was intended to address limitations of the existing MRC Water Quality Monitoring Network in terms of differentiating contaminant sources from upstream to downstream and in establishing cause-effect relationships. However, the number of stations was later reduced to 28.

Monitoring of 28 rather than 35 stations as part of the MMMAP 2011 cycle decreases the investigative power of the proposed monitoring design. Specific limitations of the sampling programme as undertaken are: (i) spatial coverage of the Mekong mainstream is not optimal, with large distances existing between some stations; (ii) several major tributaries are not included in the sampling programme; (iii) incomplete understanding of trans-boundary water quality conditions; and (iv) locations of some mainstream stations remain sub-optimal to characterise contaminant sources (e.g. the mainstream station at Vientiane is upstream of the city centre where contaminant discharges enter the river).

2.2 SCHEDULE OF THE MONITORING PROGRAMME

It was necessary to schedule sample collection later than planned. It was always intended to undertake biota, and water and sediment at different times, with biota originally scheduled for March 2011 and water and sediment sampling scheduled for May 2011. The rationale for this timing of the MMMAP sample collection was to facilitate the detection of contaminants in water and sediments during the transitional period between the dry and wet seasons. While contaminant loadings and sediment-laden runoff are typically substantially lower during the dry season, concentrations in accumulated sediments are generally expected to be higher. The proposed scheduling of biota sampling was informed by MRC’s bio-monitoring program, which has found that more consistent results are obtainable when biota and fish are sampled in March.

Circumstances dictated that the MMMAP 2011 sampling be re-scheduled, with biota sampling occurring from March through May and water and sediment sampling occurring from mid-May through June. Key reasons for delaying the sampling were: (i) to permit conduct of a preliminary survey during November and December 2010 to collect additional information needed to propose a monitoring program design; (ii) data collection as part of a review of current status of contaminants; (iii) consultations with MRC and National Mekong Committees (NMCs) on the sampling station selection;

and (iv) finalisation of the MMMAP design and logistics for undertaking field sampling in coordination with NMCs.

Implications of re-scheduling the field sampling are discussed in section 2.3 of this chapter and in Chapters 3 and 4.

2.3 SAMPLING AND ANALYTICAL METHODOLOGY

Surface water, bottom sediment and biota sampling were undertaken during the early-rainy to rainy season from March to June 2011. Field conditions encountered during this period necessitated that some adjustments be made in the sampling methodology as described in the Sampling Design report.

Safety concerns are paramount in conducting field sampling during the rainy season, when high flows and strong current pose a threat to field crews and make sample collection more challenging. Contaminant loading conditions are also changed during the rainy season, when riverbank erosion, river bottom sediment scouring and sediment content in land runoff are usually higher.

While the water sampling protocol remained unchanged, sediment and biota sampling protocols were modified on site based on best judgment of the field sampling team, and in consultation with UAE headquarters.

The proposed method of 10 Peterson grabs along a cross-river transect by dividing the river into 10 sections equally was used for sediment sampling except at some stations which had specially rocky substrate or fast flow during the sampling period. At these sites the sampling location was changed from a cross-river transect (one side to another side) to along the riverbank or from riverbank to middle of river. The actual sampling method is discussed in Section 2.3.2

In general, fish and molluscs can be sourced at most sampling stations. Exceptions are where the sites are remote or not frequented by local communities, and/or where high flow conditions are unsuitable for fishing. It is recommended that fish either be sourced from local markets, purchased from fishermen along the river, or caught with the assistance of local fishermen. Findings of the sampling for biota availability are summarised in Table 2-3: Details of actual fish sampling.

Despite the required changes, the overall field sampling remains largely consistent with the original monitoring design and sampling protocols

2.3.1 SURFACE WATER

Surface water sampling points (Table 2-3: Details of actual fish sampling) were generally accessed by boat. Coordination of the sampling site was achieved using GRAMIN® handheld GPS. Water samples were collected at the mid-depth of the middle Mekong mainstream or major tributaries using a non-metallic free-flushing Niskin water sampling bottle. The river depth was measured prior to sampling at each site. A clean-sampling technique[1] was applied while collecting samples for trace metals analysis in order to minimise sample contamination. Filtration of water samples to separate dissolved and particulate phases for metal analysis was performed in the field prior to transport back to the Laboratory of United Analyst and Engineering Consultant Co., Ltd. (UAE) for further analysis. All chemical analyses except ambient parameters were performed at UAE's laboratory.

2.3.1.1 Conventional Water Quality Parameters

Ambient water quality parameters such as pH, dissolved oxygen level, temperature and conductivity were measured in-situ, using pH meter EcoSense® model pH100 for pH and temperature, YSI 550A DO meter for dissolved oxygen, and YSI salinometer model 30 for conductivity (and salinity).

Other parameters, such as nutrient content, BOD, COD, SS, oil and grease etc were measured according to Standard Method for the Examination Water and Wastewater Analysis, 21st edition (2005).

2.3.1.2 Heavy Metals and organic micro-pollutants

Heavy metals in the dissolved phase were analysed by following the method described in Huizenga (1981) and the particulate heavy metals by the method described

Figure 2-2: Surface water sampling

Transparency measuring by Secchi Disc

Water Sampling by water sampler

Depth measuring by Echo Sounder

Coordination measuring by GPS

[1] Clean sampling technique refers to collecting sample using gloves, which minimises sample contamination.

Table 2-2: Proposed and actual sediment sampling methodology.

Station		Proposed sampling method	Actual sampling method
1.	LMH	– Sampling only from the river embankment of Lao PDR side – Take one grab every 20 metres for 10 sections along the riverbank – Keep each grab sample separate – Divide the sample from the fifth grab into 2 portions and keep one portion as grab sample – Take one scoop of sediment sample from each grab equally with plastic utensil. Combine and mix well before sub-sampling as composite sample.	Due to the fast flowing river which forms eddies and rocky shores on both sides. – Sampling from the river embankment of both sides (Myanmar and Lao PDR) – Taking one grab every 20 metres. – Keep each sectioned sample separate – Divide one sample from Lao PDR into 2 portions and keep one portion as grab sample – Take one scoop of sediment sample from each grab equally with plastic utensil. Combine and mix well before sub-sampling as composite sample.
2.	TSR	**Every station except LMH** – Measure river width and divide the river into 10 equal sections. Face current during sampling. – Take one grab from each section using Petersen grab. – Keep each grab sample separately. – Divide the sample from the fifth grab into 2 portions. Keep one portion as grab sample. – Take 1 equal scoop of sediment sample from each grab with plastic utensil. Combine and mix well before sub-sampling as a composite sample.	– Sampling only from the river section belonging to Thailand. – Divide the river section into 5 equal sections. – Take 2 grabs from each section using Petersen grab. – Keep each grab sample separately. – Divide one sample from the fifth grab (middle of the river) into 2 portions. Keep one portion as grab sample. – Take one scoop of sediment sample from each grab equally with plastic utensil. Combine and mix well before sub-sampling as composite sample.
3.	TMC		Same as TSR station
4.	TKR		As original proposed
5.	TCK		As original proposed
6.	LPB	**Every station except LMH** – Measure river width and divide the river into 10 equal sections. Fast current during sampling. – Take one sample from each section using Petersen grab. – Keep each grab sample separately. – Divide the sample from the fifth section into 2 portions. Keep 1 portion as grab sample. – Take 1 scoop of sediment sample from each grab equally with plastic utensil. Combine and mix well before sub-sampling as a composite sample.	– Sampling as original proposed method but 6 from 10 sections could not be sampled by the grab sampler due to coarse gravel riverbed. – Taking 2 grabs from the sections where sediment could be collected (stations 1, 3, 5 and 10). – Divide 1 sample from the fifth grab (middle of the river) into 2 portions. Keep 1 portion as grab sample. – Take 1 scoop of sediment sample from each grab equally with plastic utensil. Combine and mix well before sub-sampling as composite sample.
7.	LVT		As original proposed
8.	TNP		Same as TSR station
9.	LFB		As original proposed
10.	TMM		
11.	LPS		
12.	CMR		
13.	CKM		
14.	CSS		– Same as LBP station – Taking 2 grabs from sections 1, 5, 6, 9 and 10 where sediment could be collected.
15.	CSP		– Same as LBP station – Taking 2 grabs from sections 6-10 of where sediment could be collected.
16.	CSR		As original proposed
17.	CKT		
18.	CCV		
19.	CBP		
20.	CCK		
21.	CTU		
22.	CPP		
23.	CNL		
24.	CKL		
25.	VCD		
26.	VTC		
27.	VCT		

in Loring and Rantala (1995). Dissolved and particulate mercury were analysed according to US.EPA method (SW-846) (2002).

Total organochlorines and toxic substances such as phenol and pesticides were extracted and analysed following the methods described in Standard Method for the Examination of Water and Wastewater Analysis, 21st edition (2005), and only total PCB was analysed according to US.EPA method (SW-846) (1996, 2007).

2.3.2 SEDIMENT

Sediment was sampled by taking 10 grab samples along a cross-river transect by dividing the river into 10 equal sections. One grab sample collected by the Peterson grab method was taken in each section. Except at the Houa Khong station (LMH), the 10 grabs were sampled by taking one scoop every 20 metres along the riverbank with plastic utensils. The samples were combined and mixed well to make composite samples, according to the Sampling Design Report.

The sampling technique was slightly modified at a few stations according to flow conditions and river topology (Table 2-1: MMMAP Sampling station locations, rationale for inclusion in programme and matrices monitored). The sampling cross sections were varied as appropriate. The 10 replicates of Peterson grab method was used at every station, except LMH. These sampling modifications will not significantly affect the accuracy of the analytical results compared to the unmodified stations.

2.3.2.1 Sediment Characteristics

Sediment structure was identified by triangular diagram (tri-plot) using grain-size composition data which was analysed using wet sieving and sedimentation methods as described in Loring and Rantala (1995) and Sompongchaiyakul (1989).

The sediment samples were pre-treated to remove organic matter (OM) and carbonate content. They were then filtered through a 63-μm sieve. The retained portion on the sieve is called the sand fraction. The fraction that passed through the 63-μm sieve was later analysed for percentages of silt- and clay-sized particles.

The percentage of organic content in the sediment was analysed using the wet oxidation method as described in Loring and Rantala (1995).

2.3.2.2 Heavy metals and organic micro-pollutants

Heavy metals in the sediment were digested by a concentrated hydrofluoric and aqua regia method as described in Loring and Rantala (1995) and measuring metal concentration by ICP-OES. Mercury was analysed according to US.EPA method (SW-846) (2001).

Total organochlorines and toxic substances such as total PCB, HCB, pesticide and phenol etc. were analysed using the method described in US.EPA method (SW-846) (2007).

Figure 2-3: Bottom sediment sampling

2.3.3 BIOTA

For biota sampling, it proved difficult to obtain both the desired species and the required number of specimens (i.e. at least 10 individuals) at each sampling station, due to variations in river conditions and habitat along approximately 2,000 km of the lower Mekong River. Considerable variability in water velocity, riverbed texture and water temperature was observed among the main-stream stations sampled.

2.3.3.1 Fish

Based on actual fish sampling, all 19 fish species are classified as Benthopelagic fish which are defined in **http://fishbase.org/search.php** as follows:

> *Benthopelagic: Living and feeding near the bottom as well as in mid-water or near the surface feeding on benthic as well as free-swimming organisms. Many fresh-water fish are opportunistic feed-ers that forage on the bottom as well as in mid-water and near the surface.*

According to their eating behaviour, the benthopelagic fish can be divided into 3 groups as 11 species of benthopelagic carnivorous fish, 3 species of benthopelagic herbivorous fish and 5 species of benthope-lagic omnivorous fish. The details of actual fish sampling species are summarised in Table 2-3.

2.3.3.1.1 Fish Tissue Preperation

Fish tissue samples were prepared using composites of skinless fish fillets prepared from about 10 individuals of the same

Table 2-3: Details of actual fish sampling.

No.	Species	Groups	Feeding	Habitat
1	*Pangasius macronema*	Benthopelagic, Carnivorous and Potamodromous	Feeds mainly on molluscs, aquatic insects, small fish and crustaceans	Occurs in rivers, lakes and reservoirs, found in rapids, Forms large schools that move into tributary streams and flooded forests along with many cyprinids and visually oriented catfish such as Pangasius pleurotaenia
2	*Pangasius pleurotaenia*	Benthopelagic, Omnivorous and Potamodromous	Feeds on terrestrial and aquatic insects and plants	Occurs in large and medium rivers, found in rapids,
3	*Pangasius larnaudii*	Benthopelagic, Omnivorous and Potamodromous	Feeds on small fish, crustaceans, gastropods and plants.	Occurs in medium and large rivers, Found in rapids and ripples, enters flooded forests
4	*Pangasius conchophilus*	Benthopelagic, Carnivorous and Potamodromous	Feeds on finfish (nekton), crustaceans and insects, and particularly molluscs	Occurs in large rivers and enters flooded forests
5	*Laides longibarbis*	Benthopelagic, Carnivorous and Potamodromous	Feeds on fish (nekton)and zooplankton	Inhabits large rivers with turbid and slow or standing waters
6	*Hemibagrus wyckioides*	Demersal, Benthopelagic, Carnivorous and Potamodromous	Feed mainly on fish and crustaceans	Occurs in large upland rivers with rocky bottom and enters flooded forests
7	*Hemibagrus nemurus*	Benthopelagic, Carnivorous and Potamodromous	Feed mainly on aquatic insects, crustaceans and fish	Occurs in most habitat types, but most frequent in large muddy river with slow current and soft bottom, Enters flooded forest
8	*Hemibagrus filamentosus*	Benthopelagic, Carnivorous and Potamodromous	Feeds mainly on crustaceans and fish	Inhabits slow flowing waters, moves into flooded forests
9	*Channa striata*	Benthopelagic, Carnivorous and Potamodromous	Feeds mainly on nekton (finfish), frogs, insects, earthworms, tadpoles and crustaceans	Found mainly in swamps, but also occurs in lowland rivers, medium to large rivers, and brooks
10	*Phalacronotus micronemus*	Benthopelagic, Carnivorous and Potamodromous	Feeds on pelagic fish and crustaceans	Occurs in rivers and streams
11	*Micronema cheveyi*	Benthopelagic, Carnivorous and Potamodromous	Feeds on fish, zooplankton and aquatic insects	Inhabits rivers and canals, enters flooded fields
12	*Monopterus albus*	Benthopelagic, Carnivorous and Potamodromous	Feeds on fish, worms and crustaceans	Occurs in streamlets and canals, found in medium to large rivers
13	*Oxyeleotis siamensis*	Benthopelagic, Carnivorous	Feeds on fish and crustaceans	-
14	*Cyclocheilichthys enoplos*	Benthopelagic, Omnivorous and Potamodromous	Feeds mainly on bivalves, insect larvae, crustaceans and fish	Occurs at mid-water to bottom level of rivers
15	*Barbonymus gonionotus*	Benthopelagic, Omnivorous and Potamodromous	Feeds mainly on aquatic plants, phytoplankton, zooplankton	Occurs at mid-water to bottom depth in river, inhabits flooded forests during high water period
16	*Henicorhynchus siamensis*	Benthopelagic, Herbivorous and Potamodromous	Feeds on algae, periphyton and phytoplankton	Occurs at mid-water to bottom in large and small rivers
17	*Amblyrhynchichthys micracanthus*	Benthopelagic, Herbivorous	Feeds on periphyton and plants	Inhabits mainly rivers, with juveniles occasionally entering swamps and flooded fields
18	*Hypsibarbus vemayi*	Benthopelagic, Omnivorous and Potamodromous	Feeds mainly on aquatic plants, phytoplankton and zooplankton	Occurs at mid-water to bottom depth in river, inhabits flooded forests during high water period
19	*Puntioplites proctozysron*	Benthopelagic, Herbivorous and Potamodromous	Feeds on algae, plants	Inhabits large rivers, moves into flooded forests

species in the same size classes. Only edible muscle on the dorsal part of each individual fish was sectioned using clean-hand technique.

Moisture and fat content of fish samples were analysed following the method described in AOAC (Official Methods of Analysis, 2008).

2.3.3.1.2 Heavy Metals and Organic Micro-Pollutants

Heavy metals in the fish tissues were analysed using acid digestion and following the method described in AOAC (Official Methods of Analysis, 2005).

Total organochlorines and toxic substances, such as total PCB, HCB, pesticide and phenol etc. were analysed by ultrasonic extraction following the method described in US.EPA method (SW-846) (2007).

2.3.3.2 Molluscs

For the 2011 MMMAP protocol, it was planned to collect at least 10 individual bivalves or gastropods (snails) of the same species and size class for composing a composite sample at each sampling location. However, it was too difficult to collect the bivalves at all stations, resulting in a decision to collect more abundant gastropods than the original plan. Because they are very small, more individuals (up to >1,000 individuals for some species) were blended to make a composite sample for each species.

Characteristics of the original target bivalve and substitute gastropod species are summarised as follows:

- BIVALVES
- Bucket clams (Corbicula spp.) are distributed along the lower Mekong River, living in sandy and muddy sand habitat, feeding on detritus and benthic plankton on the riverbed. Migration is limited.

- GASTROPOD – 3 SPECIES WERE FOUND
- Golden apple snail (Pomacea canaliculata) lives in still water near the banks of large rivers, living amongst aquatic weed roots, feeding primarily on plants, short distance migration possible by closing its operculum and floating with water current.
- Polished Apple Snail (Pila polita) lives in still water near the banks of large rivers, amongst aquatic weeds, feeding primarily on plants.
- Mekong Pond snail (Mekongia sp.) is widely distributed along the Mekong River, living in sandy habitat, feeding on benthic algae.

As described above, mollusc samples of the same species were pooled and homogenized to give a composite sample for each species prior to chemical analysis. The number of individual molluscs used for each species is shown in Table 2 4. Due to the limitations and difficulty of collection of bivalve species, snails were used instead at some stations, where bivalves were not available, as indicated.

2.3.3.2.1 Mollusc Tissue Preparation

Composite tissue samples were prepared from 35 to 1,423 individual specimens,

Table 2-4: Actual biota sampling protocol.

Station		Actual Biota	Common Name /Species name	Pooled Samples	Length Range (cm.)	Weight Range (g)
2.	TSR	Mollusc (Bivalve)	Bucket Clam (*Corbicula spp.*)	1(1,096)	0.7-1.7	0.10-13.0
		Carnivorous Fish	Longbarbel Catfish (*Pangasius macronema*)	1(10)	17.4-21.3	46.0-75.5
			Yellow Catfish (*Hemibagrus nemurus*)	1(14)	15.1-18.3	38.7-69.0
4.	TKR	Mollusc (Snails)	Polished Apple Snail (*Pila polita*)	1(38)	4.2-7.8	13.8-82.1
		Carnivorous Fish	Striped Snakehead (*Channa striata*)	1(10)	20.2-28.5	71.5-184.4
			Yellow Catfish (*Hemibagrus nemurus*)	1(10)	14.0-20.0	22.1-79.3
5.	TCK	Mollusc (Bivalve)	Bucket Clam (*Corbicula spp.*)	1(805)	0.8-1.6	0.30-7.10
6.	LPB	Omnivorous Fish	Common Silver Barb (*Barbonymus gonionotus*)	1(10)	17.5-27.5	78.7-180.3
		Carnivorous Fish	Lais Catfish (*Laides longibarbus*)	1(10)	18.5-22.0	43.6-79.8
			Yellow Catfish (*Hemibagrus nemurus*)	1(10)	17.5-22.0	78.7-180.3
7.	LVT	Herbivorous Fish	Common Mud Carp (*Henicorhynchus siamensis*)	1(12)	12.8-14.5	20.2-26.0
		Carnivorous Fish	Sharp-nosed Catfish (*Pangasius conchophilus*)	1(4)	37.0-60.0	400.0-1,500
			Asian Red Tail Catfish (*Hemibagrus wyckioides*)	1(10)	17.8-23.5	38.5-84.3
8.	TNP	Mollusc (Snail)	Mekong Pond Snail (*Mekongia sp.*)	1(500)	1.7-2.1	2.44-6.83
9.	LFB	Herbivorous Fish	Bliunt Face Barb (*Amblyrhynchichthys micracanthus*)	1(8)	12.9-15.5	22.3-43.7
		Carnivorous Fish	Sheatfish (*Phalacronotus micronemus*)	1(10)	18.5-22.5	47.9-96.5
			Yellow Catfish (*Hemibagrus nemurus*)	1(10)	15.5-20.0	41.6-61.7
10.	TMM	Mollusc (Bivalve)	Bucket Clam (*Corbicula spp.*)	1(800)	0.7-1.7	0.10-1.30
		Omnivorous Fish	Sharp-Belly Catfishes (*Pangasius pleurotenia*)	1(20)	16.6-20.0	23.5-43.0
			Soldier River Barb (*Cyclocheilichthys enoplos*	1(14)	17.5-23.7	45.1-120.5
11.	LPS	Mollusc (Snail)	Mekong Pond Snail (*Mekongia sp.*)	1(350)	1.2-1.8	2.46-5.82
		Carnivorous Fish	Sheatfish (*Micronema cheveyi*)	1(10)	16.0-18.5	19.5-28.4
			Yellow Catfish *(Hemibagrus filamentus*)	1(10)	22.0-28.0	77.3-149.0
16.	CSR	Omnivorous Fish	Silver Barb (*Hypsibarbus vernayi*)	1(10)	19.5-27.0	87.8-236.0.4
		Carnivorous Fish	Long-barbel Catfish (*Pangasius macronema*)	1(10)	16.7-19.3	20.9-37.2
			Yellow Catfish (*Hemibagrus nemurus*)	1(10)	25.5-30.0	132.9-237.4
17.	CKT	Carnivorous Fish	Long-barbel Catfish (*Pangasius macronema*)	1(10)	16.9-20.0	23.5-39.8
19.	CBP	Mollusc (Snail)	Polished Apple Snail (*Pila polita*)	1(51)	3.6-7.0	4.8-34.5
		Carnivorous Fish	Striped Snakehead (*Channa striata*)	1(10)	29.5-35.5	245.1-443.0
			Swamp Eel (*Monopterus albus*)	1(10)	50.5-66.0	32.8-247.6
21.	CTU	Mollusc (Bivalve)	Bucket Clam (*Corbicula spp.*)	1(400)	1.1-3.0	0.70-6.20
22.	CPP	Herbivorous Fish	Smith's barb (*Puntioplites proctozysron*)	1(10)	13.2-18.0	30.1-91.2
		Carnivorous Fish	Sleeper (*Oxyeleotris siamensis.*)	1(10)	7.5-13.0	7.4-35.3
23.	CNL	Mollusc (Snail)	Golden Apple Snail (*Pomacea canaliculata*)	1(35)	2.8-6.8	4.80-33.25
		Omnivorous Fish	Common Silver Barb (*Barbonymus gonionotus*)	1(10)	13.0-21.5	34.3-139.6
		Carnivorous Fish	Swamp Eel (*Monopterus albus*)	1(10)	32.0-37.2	21.3-50.2
24.	CKL	Mollusc (Bivalve)	Bucket Clam (*Corbicula spp.*)	1(560)	1.3-2.1	1.53-4.92
		Carnivorous Fish	Striped Snakehead (*Channa striata*)	1(10)	29.0-40.0	199.5-518.9
			Yellow Catfish (*Hemibagrus nemurus*)	1(10)	27.0-62.0	220.0-281.6
25.	VCD	Mollusc (Bivalve)	Bucket Clam (*Corbicula spp.*)	1(1,403)	1.7-2.5	1.20-3.80
		Omnivorous Fish	Black spotted Catfish (*Pangasius larnaudii*)	1(12)	21.3-32.3	70.1-325.1
		Carnivorous Fish	Yellow Catfish (*Hemibagrus nemurus*)	1(10)	22.0-25.5	105.4-185.4
26.	VTC	Mollusc (Bivalve)	Bucket Clam (*Corbicula spp.*)	1(649)	1.9-4.0	1.70-6.20
		Carnivorous Fish	Long-barbel Catfish (*Pangasius macronema*)	1(19)	15.0-17.8	27.5-43.0
			Yellow Catfish (*Hemibagrus nemurus*)	1(22)	16.9-31.2	40.8-270.8
27.	VCT	Carnivorous Fish	Long-barbel Catfish (Pangasius macronema)	1(22)	13.0-17.1	18.3-41.1
28.	VTR	Carnivorous Fish	Sheatfish (Phalacronotus micronemus)	1(20)	17.8-23.8	32.6-70.6

according to species, of the same species in the same size classes. Only the muscle of the mollusc was removed from its shell using clean-hand technique. The samples were treated in the same manner as fish samples.

2.3.3.2.2 Heavy Metals and Organic Micro-Pollutants

Heavy metals in mollusc tissues were analysed using acid digestion and following the AOAC method (Official Methods of Analysis, 2005).

Total organochlorines and toxic substances such as total PCB, HCB, pesticide and phenol etc. were analysed by ultrasonic extraction using the method described in US.EPA method (SW-846) (2007).

2.4 MULTIVARIAT ANALYSIS

Human impacts on the biological integrity of water resources are complex and cumulative. Karr (1998) states that human actions jeopardise the biological integrity of water resources by altering one or more of five principal factors – (i) physical habitat; (ii) seasonal flow of water; (iii) the food base of the system; (iv) interactions within the stream biota; and (v) chemical quality of the water.

A number of studies have made use of multivariate statistical methods to seek to identify locally elevated element concentrations in environmental media. These anomalies are usually attributed to anthropogenic contamination. Multivariate statistics can be a powerful tool in discerning patterns in large collections of data.

Multivariate statistics is a form of statistics encompassing the simultaneous observation and analysis of more than one statistical variable. Methods of bivariate statistics, for example simple linear regression and correlation, are special cases of multivariate statistics in which two variables are involved.

Multivariate statistics concerns understanding the different aims and background of each of the different forms of multivariate analysis, and how they relate to each other. The practical implementation of multivariate statistics to a particular problem may involve several types of univariate and multivariate analysis in order to understand the relationships between variables and their relevance to the actual problem being studied. There are many different models of which Principal Components Analysis (PCA) and Cluster Analysis are included, each with its own type of analysis. PCA and Cluster analysis were chosen to treat the MMMAP data set.

2.4.1 PRINCIPAL COMPONENTS ANALYSIS (PCA)

Principal Components Analysis (PCA) is a multivariate statistical technique that can be used to simplify large data sets and convert data into a graphical form, allowing similarities and differences between data sets to be visualised more readily.

PCA as a multivariate analytical tool was used to reduce the set of original variables, and to extract a small number of the dominant principal components to explain the relationships among the observed variables. The number of principal components is less than or equal to the number of original variables. This transformation is defined in such a way that the first principal component has as high a variance as possible (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it be orthogonal to (uncorrelated with) the preceding components. Principal components are guaranteed to be independent only if the data set is jointly normally distributed. To obtain more clear features, Variamax rotation with Kaiser Normalisation was used.

Bivariate scatter plots are used for comparing the scatter or clustering of points given 2 dimensions. They can be used to develop regression lines or to incorporate 3 factors (3-dimensional).

In this study, the SPSS 16 is used for PCA. In this case study we try to track the data set from 2 groups (mainstream and tributaries) and 4 groups from 4 region sections detailed as follows:

- Mekong River Section 1: Station 1-9
- Mekong River Section 2: Station 10-17
- Mekong River Section 3: Station 18, 21-28
- Tonle Sap: Station 19-20

Table 2-5: MMMAP water quality criteria.

Parameter	WQCA	WQCH
General parameters and nutrients		
BOD (mg/L)	3	4
DO (mg/L)	>5	≥6
pH	6.0-9.0	6.0-9.1
Temp. (°C)	Natural	natural
Oil & Grease (mg/L)	-	-
Salinity (ppt)	-	-
Conductivity (µmho/cm)	-	700-1500
SS (mg/L)	-	-
COD (mg/L)	-	5
Chlorophyll (mg/m^3)	-	-
Total Dissolved Nitrogen (mg/L)	-	-
Total Dissolved Phosphorus (mg/L)	-	-
Pesticide		
Total PCB (µg/L)	-	-
Hexachlorobenzene(HCB) (µg/L)	-	-
Total Organochlorine Pesticide (mg/L)	0.05	0.05
p,p' –DDT (µg/L)	-	-
p,p' –DDE (µg/L)	-	-
p,p' –DDD (µg/L)	-	-
Endrin Aldehyde (µg/L)	-	-
EndosulfanSulphate (µg/L)	-	-
Heptachlor (µg/L)	-	-
Heptachlor Epoxide (µg/L)	-	-
α-Hexachlorocyclohaxane (µg/L)	-	-
γ-Hexachlorocyclohaxane (µg/L)	-	-
Chlordane (CHL) (µg/L)	-	-
Heavy metals (particulate)		
Mercury (Hg) (µg/g)	-	-
Cadmium (Cd) (µg/g)	-	-
Lead (Pb) (µg/g)	-	-
Arsenic (As) (µg/g)	-	-
Chromium (Cr) (µg/g)	-	-
Nickel (Ni) (µg/g)	-	-
Copper (Cu) (µg/g)	-	-
Heavy metals (dissolved)		
Reactive Mercury (Hg) (ng/L)	-	-
Total Mercury (Hg) (ng/L)	1000	2000
Cadmium (Cd) (µg/L)	5	5
Lead (Pb) (µg/L)	50	50
Arsenic (As) (µg/L)	10	10
Chromium (Cr) (µg/L)	50	50
Nickel (Ni) (µg/L)	-	-
Copper (Cu) (µg/L)	-	-
Toxic substance		
Cyanide (CN) mg/L	0.005	0.01
Phenols (mg/L)	0.005	0.005

WQCA = MRC Criteria and target value for the protection of aquatic life
WQCH = MRC Criteria and target value for the protection of human health

Table 2-6: MMMAP sediment quality criteria (dry weight basis).

Parameters	ANZECC*	
	Upland River	Lowland River
General parameters		
Organic Matter (%w/w)	-	-
Pesticide		
Total PCB (mg/kg)	0.023	-
Hexachlorobenzene(HCB) (mg/kg)	-	-
Total Organochlorine Pesticide	-	-
p,p' –DDT (mg/kg)	0.0016	0.046
p,p' –DDE (mg/kg)	0.0022	0.027
p,p' –DDD (mg/kg)	0.002	0.020
Endrin Aldehyde (mg/kg)	-	-
EndosulfanSulphate (mg/kg)	-	-
Heptachlor (mg/kg)	-	-
Heptachlor Epoxide (mg/kg)	-	-
α-Hexachlorocyclohaxane (μg/L)	-	-
γ-Hexachlorocyclohaxane (μg/L)	-	-
Chlordane (CHL)(mg/kg)	0.0005	0.006
Heavy metals		
Mercury (Hg)(mg/kg)	0.15	1.00
Cadmium (Cd) (mg/kg)	1.5	10
Lead (Pb) (mg/kg)	50	220
Arsenic (As) (mg/kg)	20	70
Chromium (Cr) (mg/kg)	80	370
Nickel (Ni) (mg/kg)	21	52
Copper (Cu) (mg/kg)	65	270
Aluminum (Al) (mg/kg)	-	-
Litium (Li) (mg/kg)	-	-

*ANZECC = Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

2.5 WATER, SEDIMENT AND BIOTA STANDARDS AND CRITERIA

While individual LMB countries possess national standards, regional freshwater quality standards have not yet been formulated. However, MRC has developed technical criteria for the protection of human health and aquatic life to assess and report on general water quality conditions. A limitation of the MRC criteria is that only selected parameters are covered, limiting their applicability in comprehensive monitoring programs such as the MMMAP where a larger number of parameters are being monitored. The same limitation applies to other regional and international standards that could appropriately be applied in the Mekong River, such as the standards developed for rivers in tropical northern Australia.

For this reason, water analytical results for the MMMAP have been compared to the MRC Water Quality criteria summarised in Table2-5. Similarly, sediment results are compared to criteria chosen for tropical environments as summarised in Table 2 66. For biota, available international standards and criteria, including FDA and EPA Safety Levels in Regulations and Guidance, CODEX STANDARD 1993-1995, and EU 2006 are being applied as summarised in Table 2-7.

Table 2-7: MMMAP biota criteria (wet weight basis).

Parameters	FDA and EPA safety levels in regulations and guidance (all fishes)	CODEX STANDARD 1993–1995		European Commission 2006	
		Fish	Molluscs	Fish	Molluscs
Pesticide					
Total PCB (mg/kg)	2.0	-	-	-	-
Hexachlorobenzene(HCB) (mg/kg)	-	-	-	-	-
Total Organochlorine Pesticide					
p,p' –DDT (mg/kg)	5.0	-	-	-	-
p,p' –DDE (mg/kg)	5.0	-	-	-	-
p,p' –DDD (mg/kg)	-	-	-	-	-
Endrin Aldehyde (mg/kg)	-	-	-	-	-
EndosulfanSulphate (mg/kg)	-	-	-	-	-
Heptachlor (mg/kg)	0.3	-	-	-	-
Heptachlor Epoxide (mg/kg)	0.3	-	-	-	-
α-Hexachlorocyclohaxane (μg/L)	-	-	-	-	-
γ-Hexachlorocyclohaxane (μg/L)	-	-	-	-	-
Chlordane (CHL)(mg/kg)	0.3	-	-	-	-
Heavy metals					
Mercury (Hg)(mg/kg)	-	-	-	1	-
Cadmium (Cd) (mg/kg)	-	1	1	0.05	1
Lead (Pb) (mg/kg)	0.3	0.3	-	0.2	1.5
Arsenic (As) (mg/kg)	-	-	-	-	-
Chromium (Cr) (mg/kg)	-	-	-	-	-
Nickel (Ni) (mg/kg)	-	-	-	-	-
Copper (Cu) (mg/kg)	-	-	-	-	-

FDA and EPA = Fish and Fishery Products Hazards and Controls Guidance, 4th Edition, 2011
CODEX = CODEX Alimentarius Commission. CODEX STANDARDS for Fish and. Fishery Products, 1993-1995
European Commission = Commission Regulation (EC) No. 1881/2006 of 19 December 2006

3. RESULTS AND DISCUSSIONS

3. RESULTS AND DISCUSSIONS

This chapter includes the analytical results of surface water, sediment and biota. An interpretation of the results is also analysed by selected multivariate analysis, hierarchy cluster analysis (HCA) and principal component analysis (PCA). The results are shown by comparing: i) Mekong mainstream (17 stations) and tributaries (11 stations); and ii) 4 Mekong sections which are referred to in 4 groups according to the region. The Mekong sections 1, 2, 3 and Tonle Sap represent the upper (stations 1–9), middle (stations 10–17), and lower parts of the LMB (stations 21–28) and Tonle Sap (stations 18–20), respectively (Figure 2-1).The results are presented and discussed according to geographical location from upstream to downstream.

The results of this study are compared with a number of previous studies including water quality monitoring networks under MRC from Year 2005 to 2010 as well as national and regional studies in MRC member countries.

The comparison for different stations and sections are presented in bar graphs. The abbreviations for each station are listed in Table 2-1. The following colour codes are used to identify the countries:

- Green bars represent the stations in Lao PDR
- Blue bars represent the stations in Thailand
- Yellow bars represent the stations in Cambodia
- Purple bars represent the stations in Viet Nam.

The mainstream and tributaries are represented by solid colour and striped bars respectively. The sequence of stations starts from the first station upstream at Houa Khong (LMH) in Lao PDR to the last station downstream at My Thuan (VTR) in Viet Nam.

3.1 SURFACE WATER

3.1.1 PHYSICOCHEMICAL AND CONVENTIONAL PARAMETERS

Ranges and average values for physicochemical and conventional parameters in the Mekong River mainstream and tributary stations are summarised in Tables 3-1 and 3-2 and Figures 3-1 to 3-11.

Table 3-1: Range (minimum – maximum) and average (± standard deviation) of physicochemical properties of water in the Mekong River mainstream and tributaries.

Parameter	Salinity (ppt)	Conductivity (μmhos/cm)	Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Chlorophyll a (mg/m³)	Suspended Solid (mg/L)	Oil & Grease (mg/L)	BOD (mg/L)	COD mg/L)	TDN (mg/L)	TDP (mg/L)
THIS STUDY												
Mekong River Mainstream												
Min – Max	0.1	169 – 310	24.0 – 32.0	6.8 – 7.6	4.7 – 9.7	2.4 – 9.5	8 – 353	<1.0 – 1.4	<1.0 – 10.4	<5.0 – 21.9	0.46 – 0.85	0.01 – 0.21
Avg ± SD	0.1	229 ± 40	28.9 ± 2.6	7.2 ± 0.2	7.6 ± 1.1	5.3 ± 2.4	83 ± 85	0.3 ± 0.5	2.3 ± 2.6	8.2 ± 4.7	0.62 ± 0.10	0.04 ± 0.05
Tributaries												
Min – Max	0.0 – 0.1	57 – 227	26.0 – 33.0	7.0 – 7.7	4.9 – 11.8	2.5 – 27.9	6 – 680	<1.0 – 2.2	<1.0 – 5.8	6.1 – 32.8	0.30 – 1.02	<0.01 – 0.08
Avg ± SD	0.1	124 ± 59	29.3 ± 2.0	7.3 ± 0.2	7.5 ± 1.7	9.2 ± 7.9	119 ± 192	0.9 ± 0.6	2.1 ± 1.7	15.0 ± 7.8	0.70 ± 0.20	0.02 ± 0.02
Other studies for Mekong River Mainstream												
Marine Department: Thailand (2009) (Chiang Sean Pier 2, construction phase monitoring near Chiang Sean Pier 1) – near TMC of MMMAP												
Min – Max	–	–	–	7.3 – 7.5	6.0 – 6.8	–	31.2 – 140.0	<0.1	2.4 – 2.6	–	–	–
Avg ± SD	–	–	–	7.4 ± 0.1	6.4 ± 0.6	–	85.6 ± 76.9	<0.1	2.5 ± 1.4	–	–	–
MRC (2007) (Diagnostic 2003–2004)												
Min – Max	–	58 – 328	19.4 – 34.3	7.8 – 9.4	6.6 – 12.3	–	–	–	–	2.0 – 78.0	–	–
Avg ± SD	–	217 ± 88	28.4 ± 4.1	8.4 ± 0.4	8.0 ± 1.3	–	–	–	–	23.6 ± 29.9	–	–
MRC (2011) (WQMN 2005–2010)												
Min – Max	–	13 – 412	13.0 – 33.2	6.0 – 9.7	0.6 – 15.0	–	1 – 1,876	–	–	0 – 16.4	–	–
Avg ± SD	–	187 ± 76	26.3 ± 3.1	7.3 ± 0.5	6.5 ± 1.8	–	144 ±194	–	–	3.0 ± 2.0	–	–
MRC (2008) Biomonitoring survey in LMB, MRC Tech Paper No. 27						–	–	–	–	–	–	–
Min – Max	–	36 – 1,210	22.1 – 32.7	6.44 – 8.60	4.9 – 9.0	–	–	–	–	–	–	–
Avg ± SD	–	–	–	–	–	–	–	–	–	–	–	–

Table 3-1: Range (minimum – maximum) and average (± standard deviation) of physicochemical properties of water in the Mekong River mainstream and tributaries.

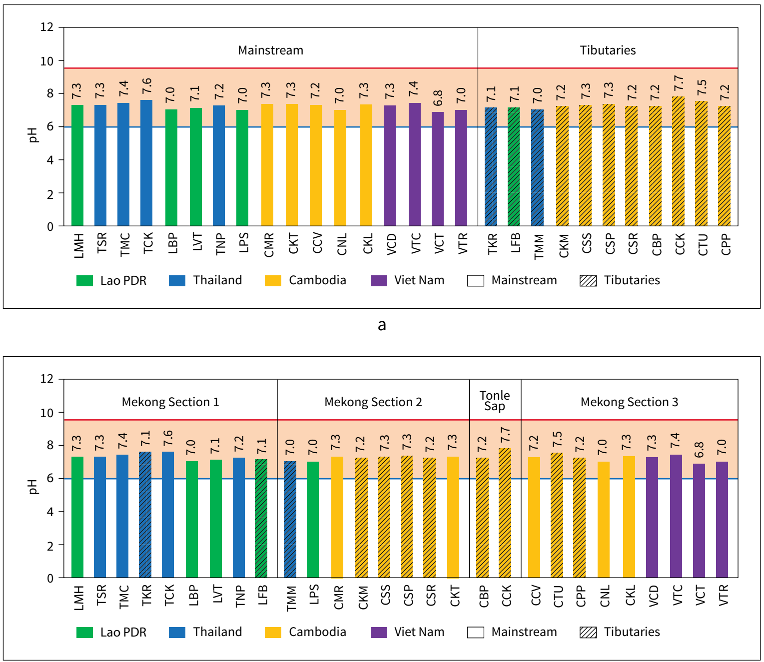
Parameter	Salinity (ppt)	Conductivity (μmhos/cm)	Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Chlorophyll a (mg/m³)	Suspended Solid (mg/L)	Oil & Grease (mg/L)	BOD (mg/L)	COD mg/L)	TDN (mg/L)	TDP (mg/L)
Other studies for tributaries of Mekong River												
Marine Department: Thailand (2009) (Chiang Sean Pier 2, construction phase monitoring) – in Kok River												
Min – Max	-	-	-	7.2	5.6 – 6.1		132 – 256	< 0.1	2.3 – 2.4	-	-	-
Avg ± SD	-	-	-	7.2	5.9 ± 0.4		194 ± 88	< 0.1	2.4 ± 0.07	-	-	-
Marine Department: Thailand (2007) – Mun River												
Min – Max	0.0 – 0.9	57 – 2,022	22.2 – 35.0	7.1 – 8.6	4.5 – 8.5	-	0 – 73	0.0 – 0.9	0.1 – 3.5	-	-	-
Avg ± SD	0.2 ± 0.2	432 ± 371	28.8 ± 3.6	7.6 ± 0.3	6.4 ± 0.9	-	30 ± 17	0.0 ± 0.1	1.3 ± 1.0	-	-	-
MRC (2007) (Diagnostic 2003) –2004)												
Min – Max	–	58 – 328	19.4 – 34.3	7.8 – 9.4	6.6 – 12.3	–	–	–	–	2.0 – 78.0	–	–
Avg ± SD	–	217 ± 88	28.4 ± 4.1	8.4 ± 0.4	8.0 ±1.3	–	–	–	–	23.6 ± 29.9	–	–
MRC (2011) (WQMN 2005–2010)												
Min – Max	–	9 – 352	18-2 – 34.0	6.2 – 8.9	0.8 – 12.0	–	1 – 752	–	–	0.2 – 13.5	–	–
Avg ± SD	–	142 ± 83	27.5 ± 3.0	7.3 ± 0.4	6.9 ±1.6	–	75 ±105	–	–	3.8 ± 2.7	–	–
WATER QUALITY CRITERIA												
WQCA	–		natural	6.0 – 9.0	$\geq$5	–	–	–	3	–	–	–
WQCH	–	700-1500	natural	6.0 – 9.0	$\geq$6	–	–	–	4	5	–	–

Table 3-2: Range (minimum – maximum) and average (± s.d.) of physicochemical properties of water in the Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Salinity (ppt)	Conductivity (µmhos/cm)	Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Chlorophyll a (mg/m³)	Suspended Solid (mg/L)	Oil & Grease (mg/L)	BOD (mg/L)	COD mg/L)	TDN (mg/L)	TDP (mg/L)
THIS STUDY												
Mekong River Section 1												
Min – Max	0.1	124 – 310	24.0 – 29.0	7.0 – 7.6	7.2 – 11.8	2.5 – 9.5	19 – 680	<1.0 – 1.4	<1.0 – 2.3	5.7 – 32.8	0.46 – 0.82	0.01 – 0.21
Avg ± SD	0.1	235 ± 68	26.6 ± 1.7	7.2 ± 0.2	8.6 ± 1.5	6.0 ± 2.7	182 ± 213	0.7 ± 0.4	1.4 ± 0.6	13.6 ± 8.7	0.61 ± 0.12	0.05 ± 0.06
Mekong River Section 2												
Min – Max	0.0 – 0.1	57 – 227	28.0 – 30.0	7.0 – 7.3	6.2 – 7.9	2.5 – 27.9	6 – 154	<1.0 – 1.8	<1.0 – -4.8	7.7 – 22.6	0.34 – 0.87	<0.01 – 0.03
Avg ± SD	0.1	139 ± 75	29.3 ± 0.9	7.2 ± 0.1	7.5 ± 0.6	7.3 ± 8.6	9 4 ± 43	1.0 ± 0.6	1.5 ± 1.6	11.2 ± 4.9	0.59 ± 0.18	0.02 ± 0.01
Mekong RiverSection 3												
Min – Max	0.1	190 – 222	29.0 – 32.0	6.8 – 7.5	4.7 – 7.8	2.9 – 10.4	8 – 57	<1.0 – 2.2	<1.0 – 10.4	<5 – 14.1	0.56 – 0.85	0.02 – 0.05
Avg ± SD		204 ± 11	30.7 ± 1.2	7.2 ± 0.2	7.0 ± 0.9	5.4 ± 2.5	27 ± 17	0.7 ± 0.6	4.1 ± 3.1	6.3 ± 3.5	0.68 ± 0.11	0.03 ± 0.01
Tonle Sap												
Min – Max	0.1	99	32.0 – 33.0	7.2 – 7.7	4.9 – 7.4	9.0 – 19.2	34 – 45	<1.0	2.7 – 3.5	14.2 – 22.0	0.40 – 1.02	0.04 – 0.08
Avg ± SD	0.1	99 ± 0	32.5 ± 0.7	7.5 ± 0.4	6.2 ± 1.8	14.1 ± 7.2	39 ± 8	<1.0	3.1 ± 0.6	18.1 ± 5.5	0.71 ± 0.44	0.06 ± 0.03
Water quality criteria												
WQCA	–		natural	6.0 – 9.0	≥ 5	–	–	–	3	–	–	–
WQCH	–	700 – 1500	natural	6.0 – 9.0	≥ 6	–	–	–	4	5	–	–

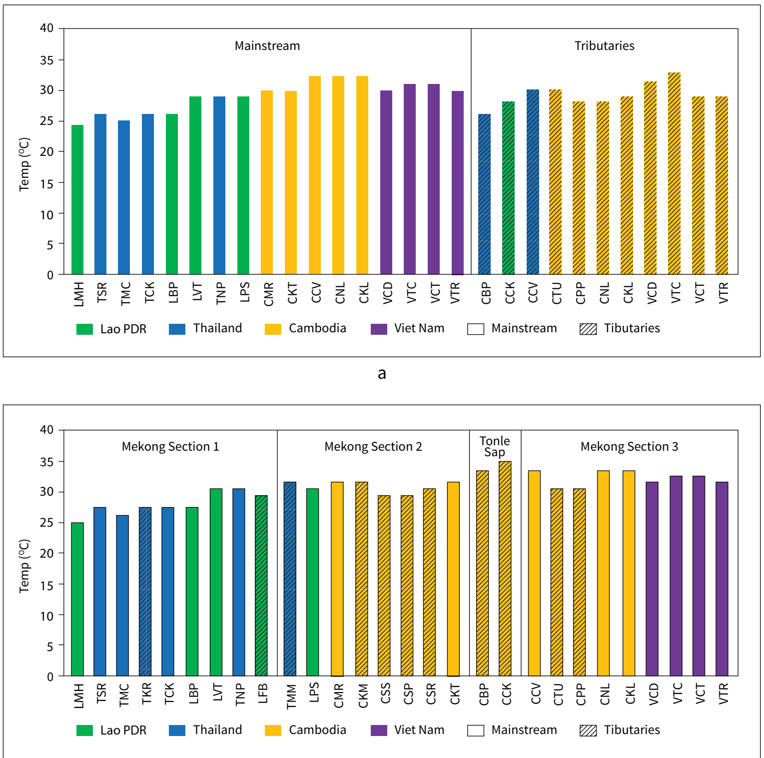
Section 1 = Stations 1 to 9 (9 stations)
Section 2 = Stations 10 to 17 (8 stations)
Section 3 = Stations 18, 21 to 28 (9 stations)
Tonle Sap = Stations19 and 20 (2 stations)

Figure 3-1: pH of surface water in the LMB (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap (The red and blue horizontal lines indicate WQCA (6.0–9.0) and WQCH (6.0–9.0) thresholds, respectively).



b

Figure 3-2: Temperature of surface water in the LMB (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap.



b

3.1.1.1 pH

The average pH in the mainstream was 7.2 ± 0.2, while in the tributaries it was 7.3 ± 0.2 (Figure 3-1(a)). The pH values of water at all stations – both mainstream and tributaries – were within the WQCA and WQCH limit ranges of 6.0–9.0. In comparison to previous studies in the LMB region, the pH values in this study were found to be in the same range as all others (Table 3-1). In comparisons between different sections of the LMB and the Tonle Sap, the same range of pH values with a small variation was found (Figure 3-1(b)).

3.1.1.2 Temperature

In general, the temperature of river water in the LMB region tended to increase from upstream to downstream (Figure 3-2). The water temperature gradually increases from 24°C, at the LMB headwater, with the distance downstream. The averages temperature in the Mekong River Sections 1, 2, 3 and Tonle Sap were 26.6 ± 1.7°C, 29.3 ± 0.9°C, 30.7 ± 1.2°C and 32.5 ± 0.7°C, respectively. The relatively high temperature in Tonle Sap is reflected from its shallow lake feature. In addition the sampling period was in early June (late summer), while the rest was sampling in early rainy season.

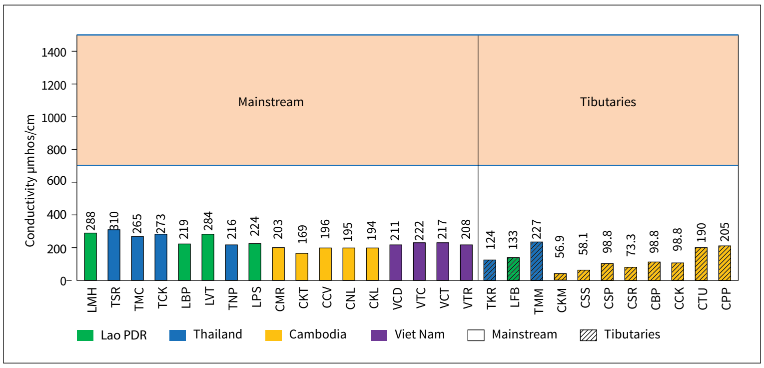
3.1.1.3 Conductivity

The average conductivity of Mekong River mainstream and tributaries were 229.1 ± 39.8 and 124.0 ± 59.1 μmhos/cm, respectively (Figure 3-3). The conductivity values at all stations, both mainstream and tributaries, were much lower than the WQCH limit range of 700–1,500 μmhos/

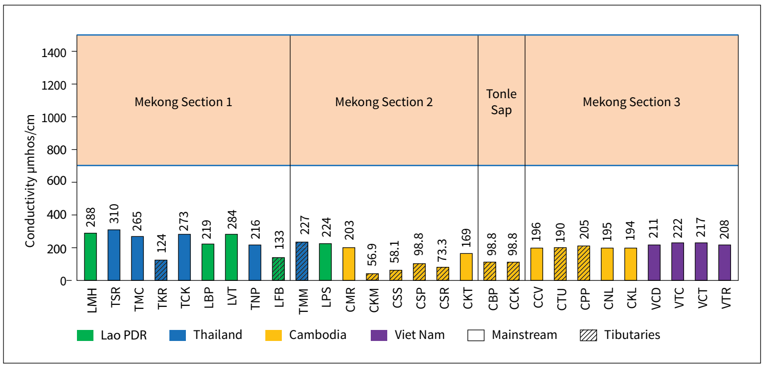
cm. The values reflect good water quality with respect to conductivity (salinity). Some elevated values of conductivity (>200 µmhos/cm) found at some locations, such as TSR, LVT, TMM and VTC, indicated a slight increase in the impact of human activities.

In comparison to the available data from other studies within the LMB region, the conductivity values reported here were found to be in the same range (Table 3-1). The high conductivity found at station TMM agrees with previous studies of the average conductivity in the Mun River (432 ± 371 µmhos/cm) reported by the Marine Department of Thailand (2007) (Table 3-1). However, it has already been noted that salt contamination from the Khorat Plateau carried by the Mun River has very little impact on salinity in the Mekong River (MRC, 2007).

Figure 3-3: Conductivity of surface water in the LMB (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap. The blue horizontal lines indicate WQCH (700–1,500 µmhos/cm) threshold.



a



b

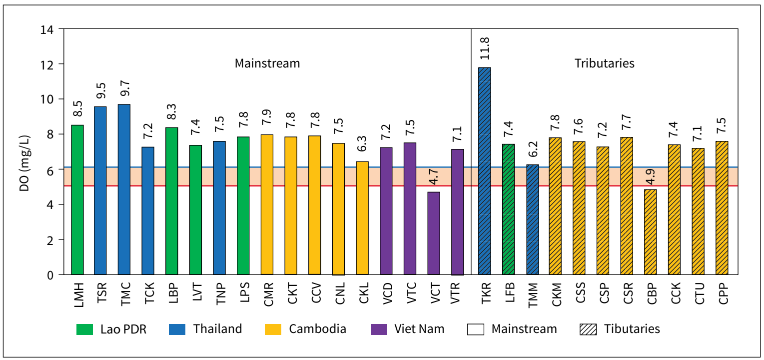
3.1.1.4 Dissolved oxygen

Most stations in the mainstream and tributaries had dissolved oxygen (DO) higher than the WQCA and WQCH guidelines of ≥ 5 and ≥ 6 mg/L, respectively (Table 3-1 and Figure 3-4). However, two stations – Can Tho (VCT) station in the Mekong mainstream Section 3 and Back Prea (CBP) station in the Tonle Sap Section had DO slightly < 5 mg/L. The DO ranges in Mekong River Sections 1 and 2 upstream were 7.2–11.8 and 6.2–7.9 mg/L, respectively, while in the Mekong River Section 3 and Tonle Sap section downstream, were 4.7–7.8 and 4.9–7.4 mg/L, respectively (Table 3-2).

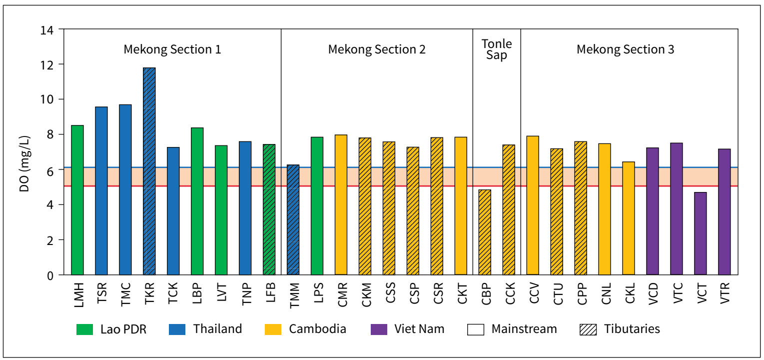
In general, high DO indicates good water quality. The DO values in some upstream stations suggested an over-saturation mainly caused by strong and rapid river flow during the sampling period (refer to Table 2-1). The DO results in this study show a wide range, which is no different to the ranges previously found in other studies (Table 3-1).

Comparing along the mainstream, there is a decreasing trend from upstream to downstream which has two possible causes, (1) the high velocity stream flow in the upstream region and (2) the higher contribution of readily oxidizable organic matter from domestic uses in the lower

Figure 3-4: Dissolved oxygen of surface water in the LMB (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap (The red and blue horizontal lines indicate WQCA (≥ 5 mg/L) and WQCH (≥ 6 mg/L) thresholds, respectively).

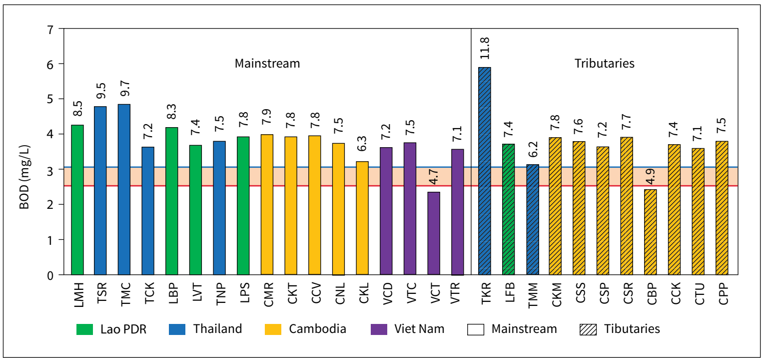


a

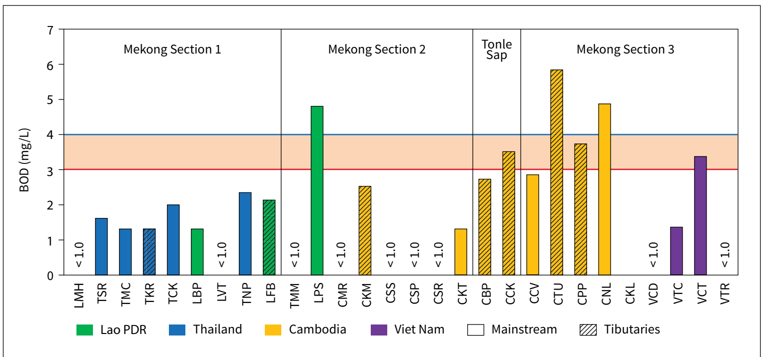


b

Figure 3-5: Biochemical Oxygen Demand (BOD) of surface water in the LMB (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap[2] (The red and blue horizontal lines indicate WQCA (< 3 mg/L) and WQCH (< 4 mg/L) thresholds, respectively).



a



b

[2] Due to the consistency between BOD and COD values at Koh Khel, CNMC requested that these values be removed from the analysis.

region, which consumes DO to oxidize these organic materials.

3.1.1.5 Biochemical Oxygen Demand

Similar to DO, the water quality in terms of Biochemical Oxygen Demand (BOD) is fairly good. Most stations in the mainstream and tributaries had BOD values not exceeding the WQCA and WQCH thresholds of < 3 and < 4 mg/L, respectively (Table 3-1 and Figure 3-5). However, elevated values were found in a few locations, namely Pakse (LPS) and Prek Kdam (CTU) (4.8 and 5.8 mg/L, respectively). The LPS sampling point was located near Pakse, with large numbers of households and vegetables growing on the riverbanks, and heavy rain had occurred prior to sampling. For CTU, the sampling point was located in the Tonle Sap River just upstream of its confluence with the Mekong River mainstream. The sampling location likely has received wastewater from Prek Kdam where the community is settled.

In comparison to the previous studies in the LMB, most rivers, such as the Mun, Kok, and Chiang Sean Rivers, had BOD values ranging from 0.1 to 3.5 mg/L (Table 3-1) which is below the WQCA (< 3 mg/L) and WQCH (< 4 mg/L). According to Sawyer et al. (2003), most pristine rivers will have a 5-day carbonaceous BOD below 1 mg/L. Moderately polluted rivers may have a BOD value in the range of 2–8 mg/L. Municipal sewage that is efficiently treated by a three-stage process would have a value of about ≤ 20 mg/L or less. Untreated sewage varies, but averages around 600 mg/L in Europe and about 200 mg/L in the U.S.

3.1.1.6 Chemical oxygen demand

Most of the mainstream and tributary stations had chemical oxygen demand (COD) higher than the WQCH threshold of 5 mg/L with an average of 8.2 ± 4.7 and 15.0 ± 7.8 mg/L in the mainstream and tributaries, respectively (Figure 3-6).

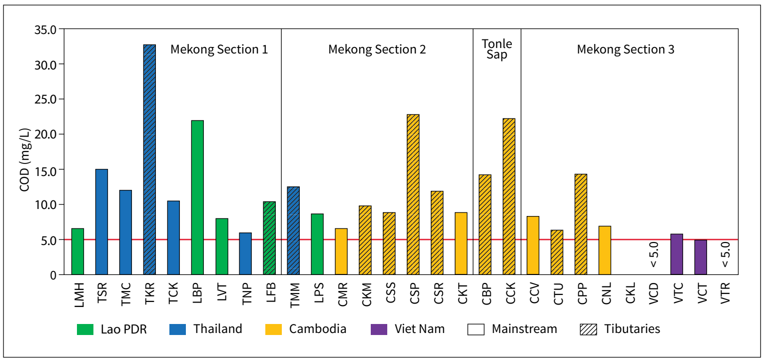
In the mainstream, COD values decrease from upstream to downstream. Higher COD was found in the tributaries. In comparison to previous water quality monitoring, MRC (2007) and MRC (2011), COD values exceeding the WQCH threshold were also found in some stations (Table 3-1). Since the WQCH threshold is as low as 5 mg/L, further assessment is needed as to whether the value is appropriate for assessing Mekong River water which is located in a tropical region where high levels of humic substances and highly degradable dissolved organic matter (DOM), are generally present.

3.1.1.7 Suspended Solid (SS)

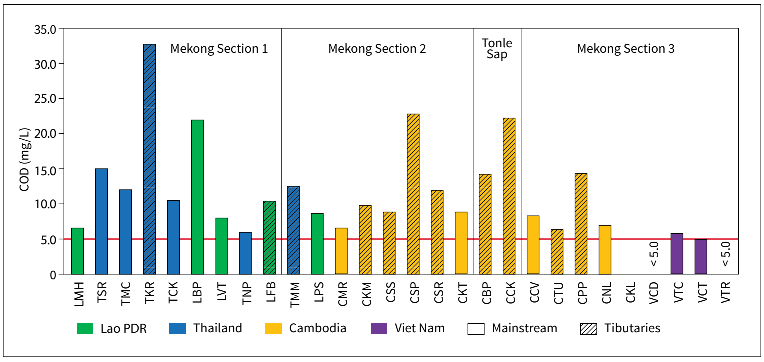
The average values of suspended solids (SS) in the mainstream and tributaries were 83 ± 85 and 119 ± 192 mg/L, respectively (Table 3-1 and Figure 3-7). The SS ranges were large with the values of 8 to 353 and 6 to 680 mg/L in the mainstream and tributaries, respectively. In general, the SS concentration appeared to decrease downstream due to the sedimentation of larger particulate matters at the upstream stations (Figure 3-7).

The SS concentrations upstream were high due to high river water flow in the rainy season and heavy rain causing sediment

Figure 3-6: COD of surface water in the LMB (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap (The red and blue horizontal lines indicate WQCH (<5 mg/L) thresholds)[3].



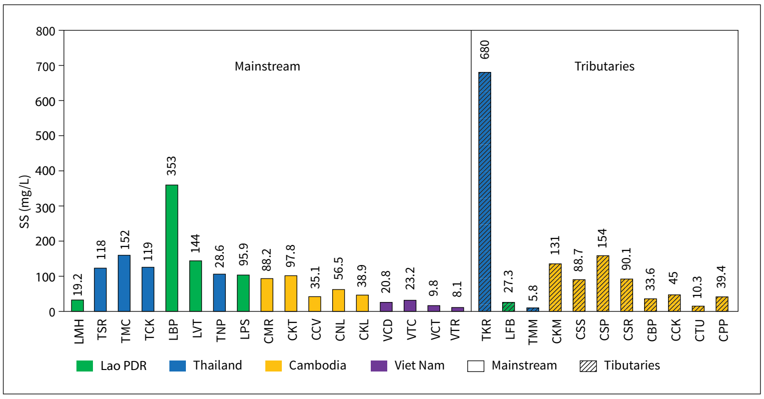
a



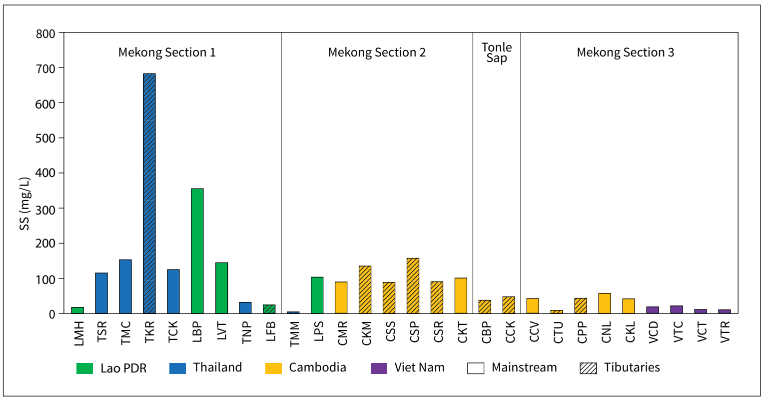
b

[3] Due to the consistency between BOD and COD values at Koh Khel, CNMC requested that these values be removed from the analysis.

Figure 3-7: Suspended solids of surface water in the LMB (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap.



a



b

runoff (especially LPB station). Referring to Table 2-1, the sampling team reported a strong and rapid flow with brownish and turbid water at all upstream stations. The extremely high SS in TKR was caused by turbulent flows at the Kok River mouth before it joins the Mekong mainstream. The narrow width compared to upstream resulted in re-suspension of bottom sediment (refer to Table 2-1). The low SS value observed at LMH station was a low estimate due to the very high turbulence in the river making it impossible to collect a water sample from the mid-stream. The sample was collected near the riverbank instead. The result at TNP station may be affected by large quantities of water lettuce floating near the Lao PDR side, which caused a slowing of the water flow.

3.1.1.8 Oil and grease

The oil and grease (O&G) values found in the Mekong River were low, mostly <1.0 mg/L. As shown in Table 3-1 and Figure 3-8, the O&G values ranged from <1.0–1.4 and <1.0–2.2 mg/L in the mainstream and tributaries, respectively. A few stations had slightly elevated O&G, such as CPP (Phnom Penh Port) (2.2 mg/L), Luang Prabang (LPB) (1.2 mg/L) and Vientiane (LVT) (1.4 mg/L). According to the sampling team (refer to Table 2-1), navigation/ port activities and rubbish from the high density community surrounding CPP were the possible sources for high O&G at this station. For LPB, it was likely that high levels of navigation activity in the river and heavy rain before and during sampling might be the sources. Runoff from the community caused by heavy rain before and during sampling was a possible reason for high O&G at LVT.

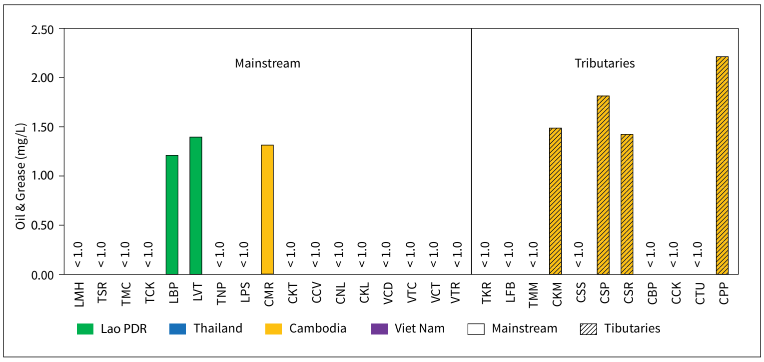
3.1.1.9 Chlorophyll a

Chlorophyll a as a photosynthetic pigment integrating all types of algae is a measurable parameter for whole algal production. It represents the biological response of the aquatic system, and is commonly employed as an indicator of nutrient enrichment or eutrophication (Bricker et al., 1999). However, relationships between chlorophyll a and both nutrient loading and river discharge varied seasonally. Concentrations greater than about 7–10 mg/m3 indicate eutrophic conditions and greater than 20–30 mg/m3 are usually considered to be associated with algal blooms (Robertson et al., 2003).

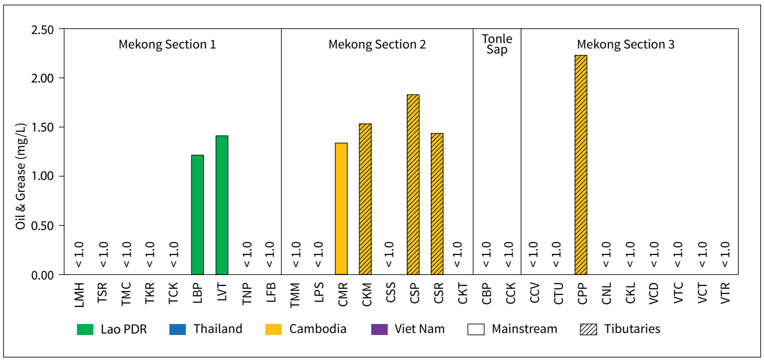
In this study, average chlorophyll a values in the mainstream and tributaries were 5.2 ± 2.4 and 9.2 ± 7.9 mg/m3, respectively. The values tend to be higher in the tributaries, with possible eutrophic conditions (Robertson et al., 2003), than in the mainstream (Table 3-1 and Figure 3-9). The results indicate that, in general, the tributaries received more nutrients and/or less dilution than the mainstream.

The highest chlorophyll a was found at Kong Chiam (TMM) in the Mun River and Phnom Krom (CCK) in the Great Lake with values of 27.9 and 19.2 mg/m3, respectively (Figure 3-9). The lowest concentration of suspended solids (SS) was also found at TMM (Figure 3-7). Under conditions of excess nutrients, high penetration of light due to the low SS promotes photosynthesis and

Figure 3-8: Oil and grease of surface water in the LMB (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap.

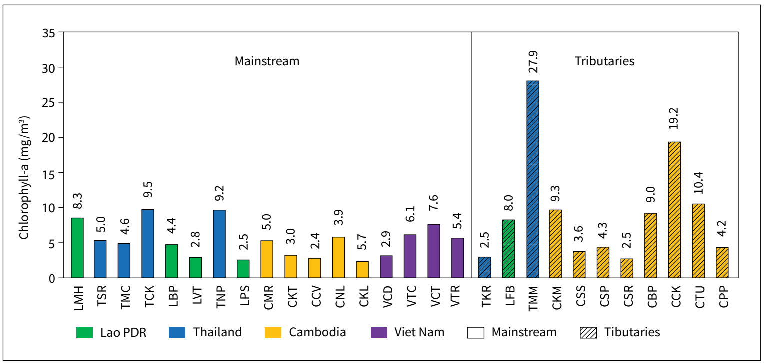


a



b

Figure 3-9: Chlorophyll a of surface water in the LMB (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap.



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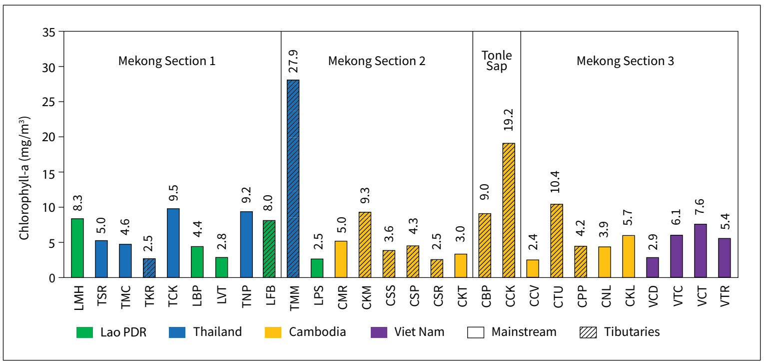
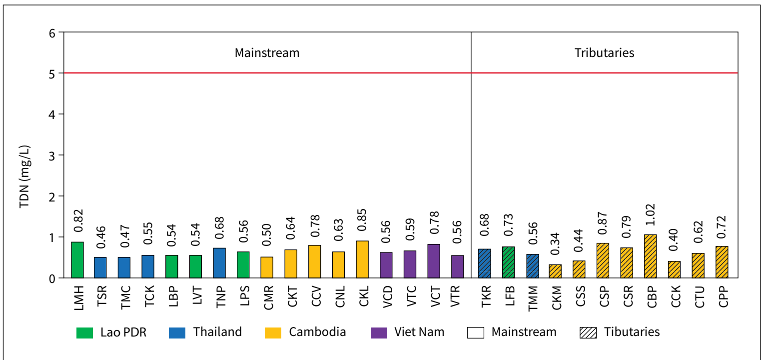


b

Figure 3-10: Total dissolved nitrogen of surface water in (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap (The red and blue horizontal lines indicate WQCA (< 5 mg/L) and WQCH (< 5 mg/L) thresholds, respectively).



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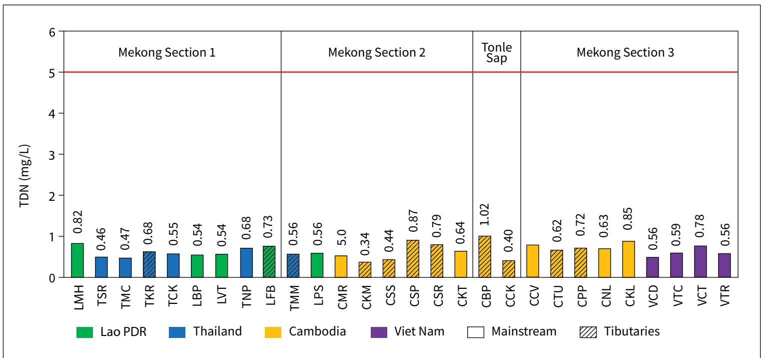


b

increases chlorophyll a concentration. The second highest chlorophyll a value occurred at CCK was likely attributable to receiving drainage water from the surrounding area and a longer residence time of water within the lake. Moreover, the hydrological regime of the Great Lake is different to other stations along the LMB.

3.1.1.10 Total dissolved nutrients

Total dissolved nitrogen (TDN) is comprised of dissolved inorganic nitrogen (DIN) and dissolved organic nitrogen (DON). There is evidence that DON, particularly urea, may be important in triggering harmful algal blooms. Phosphorus is also very important as a limiting nutrient, particularly in fresh water as well as in tropical and subtropical estuarine marine systems. Total dissolved phosphorus (TDP) includes dissolved organic phosphorus (DOP) and orthophosphate which is a dissolved inorganic form of phosphorus (DIP). The concentration of orthophosphate is very low and is rapidly recycled.

The Nutrients Workgroup of the Advisory Committee on Water Information (ACWI) of USA recommends that TDN and TDP be measured. The advantage of measuring TDN and TDP is that it provides a better estimate of the N that is likely to be most available to phytoplankton, and gives more detailed information about the most available pools of P (ACWI, 2007).

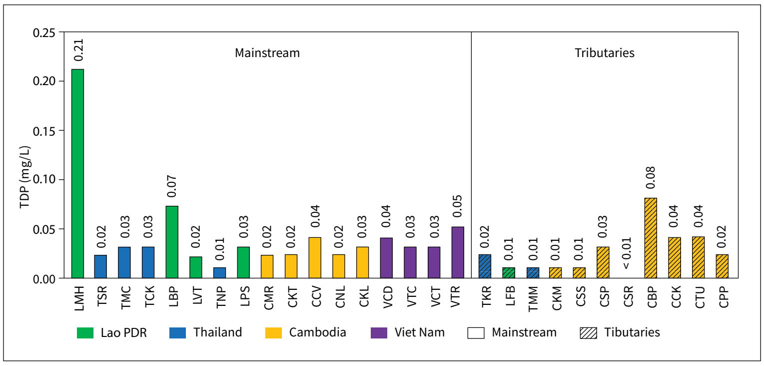
As shown in Figures 3-10 and 3-11, total dissolved nitrogen (TDN) concentration had comparable ranges and averages in both the Mekong mainstream and tributaries, whereas total dissolved phosphorus (TDP) was comparatively lower in the tributaries with the exception of the Tonle Sap region. TDN concentration ranged from 0.5 to 0.9 mg/L in the Mekong mainstream, and from 0.3 to 1.0 mg/L in the tributaries. TDP values ranged from 0.01 to 0.21 mg/L in the mainstream, and from 0.01 to 0.08 mg/L in the tributaries.

The highest TDP concentration was found at Houa Khong (LMH). The highest TDN in the upper half of the LMB mainstream was also found at LMH. The high values of total dissolved nutrients at LMH suggest an upper Mekong source. According to the pollution review report, this evidence was probably caused by transboundary pollution carried over from Yunnan province of PR China. The Lancang River (the name of the Mekong River in PR China) flows roughly 2,000 km from its source and drains a catchment of 165,000 km^2. Before entering the upper section of the LMB, the river flows through Yunnan province where agriculture is the most important sector, accounting for roughly 30% of the province's GDP. The high value of TDP at Luang Prabang (LPB) station in the mainstream is likely to be affected by a flushing of phosphorus from the drainage area by rainwater at sampling.

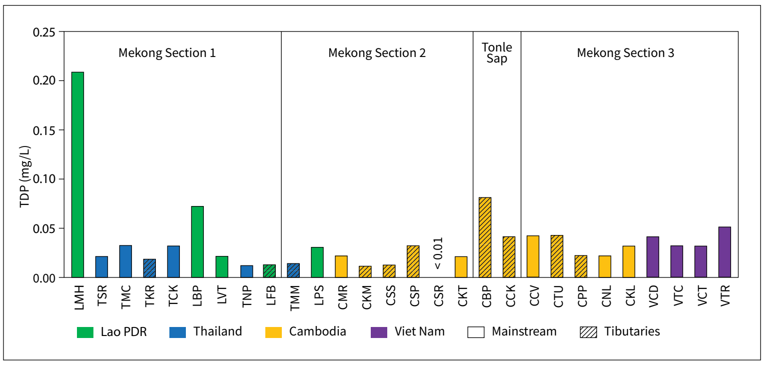
The high value of total dissolved nutrients, both TDN and TDP, found at Back Prea (CBP) station, was probably due to inputs of domestic nutrients from the community (see Figure 2-2). The sampling station was located in Stoeng Sangke River where settlement occurs along the river. According to observations of the sampling team, domestic waste was discharged directly to the river.

However, TDN and TDP levels in the LMB were generally considered not high. Although the effect of human activities on riverine N exports in the tropics is still poorly understood, we know that nitrogen export in the pristine rivers and streams in the tropics is high compared to that in the temperate zone (Martinelli et al., 2010), and N concentrations decrease as river runoff increases in both pristine and affected regions (Lewis et al., 1999).

Figure 3-11: Dissolved phosphorus of surface water in (a) mainstream and tributaries, and (b) Mekong River Sections 1, 2, 3 and Tonle Sap.



a



b

3.1.2 DISSOLVED AND PARTICULATE HEAVY METALS

The dissolved and particulate heavy metal in surface water was analysed for 21 sampling stations. The 7 stations which were not sampled are: Xe Bang Fai (LFB), Siem Pang (CKM), Adoung Meas (CSS), Lumpat (CSP), Sekong River mouth (CSR), Back Prea (CBP) and Phnom Krom (CCK). All these stations are located in tributaries. Due to the limitations of the program, the stations which presented the dominant point sources were selected to study. Dissolved metals, known as bio-available fraction, are generally low throughout the LMB (Table 3-3 and 3-4). It should be noted that the WQCH and WQCA thresholds for dissolved metal concentration were not exceeded at any stations and levels were well below the thresholds, particularly for mercury.

Comparison of dissolved and particulate metal concentration in surface water of the mainstream and tributaries in the LMB is presented in Figure 3-12a to Figure 3-16a. The comparison among the Mekong River sections is shown in Figure 3-12b to Figure 3-16b.

In natural media, metal contaminants undergo reactions with ligands in water and with surface sites on the solid materials with which the water is in contact. When metals (either from a natural or anthropogenic source) enter an aquatic system, a metal ion may remain in solution (so-called dissolved form) as an aqueous ion or form organic or inorganic complexes. The metals are transported in rivers, usually in the dissolved form, or bound to suspended particulate matter, which is basically iron oxy-hydroxides or natural organic matter and which may be associated with clay minerals, aluminum as hydrous aluminum phyllosilicates, and oxides of manganese. The physical, chemical, and biological processes that occur in the system can promote the reduction of metal concentrations in solution by adsorption onto suspended particles (Hakanson et al., 2000; Allison and Allison, 2005).

Since the metals are partitioned between the solid and the liquid phases, it is thus important to calculate the respective concentrations to understand the bioavailability to the aquatic biota. Distribution of heavy metals between dissolved (bioavailable) and particulate phases can be described by a partitioning coefficient (Sirinawin et al., 1998; Andrade et al., 2006), which is defined as the ratio of the particulate metal concentration over the dissolved metal concentration.

$$K_d = \frac{C_s}{C_w}$$

where K_d is in L/kg, C_s is the particulate metal concentration (mg/kg) and C_w is the dissolved metal concentration (mg/L).

The higher the K_d value means the greater the tendency for the metals to form stable complexes in the particulate phase. On the other hand, the lower the K_d means the greater the partitioning of the metal toward the dissolved form.

Table 3-3: Range (minimum – maximum) and average (± s.d.) of dissolved and particulate heavy metals in the Mekong River mainstream and tributaries.

Parameter	Hg			Cd		Pb		As		Cr		Ni		Cu	
	D-RHg (ng/L)	D-T Hg (ng/L)	P-Hg (mg/kg)	D-Cd (µg/L)	P-Cd (mg/kg)	D-Pb (g/L)	P-Pb (mg/kg)	D-As (µg/L)	P-As (mg/kg)	D-Cr (µg/L)	P-Cr (mg/kg)	D-Ni (µg/L)	P-Ni (mg/kg)	D-Cu (µg/L)	P-Cu (mg/kg)
THIS STUDY															
Mekong River Mainstream															
Min – Max	0.14 – 4.7	0.4 – 6.1	0.10 – 2.56	< 0.05	< 0.05	0.2 – 4.9	76.8 – 293	< 0.3 – 5.5	< 0.1	< 0.15 – 1.9	20.9 – 53.5	< 0.15 – 1.7	3.48 – 22.5	< 0.15 – 4.2	8.67 – 28.1
Avg ± SD	1.0 ± 1.2	1.6 ± 1.4	0.90 ± 0.75	< 0.05	< 0.05	1.8 ± 1.5	175 ± 64.7	1.9 ± 1.7	< 0.1	0.4 ± 0.5	34.4 ± 11.3	0.7 ± 0.6	11.9 ± 5.5	1.7 ± 1.1	17.9 ± 6.19
Tributaries															
Min – Max	0.07 – 2.8	0.8 – 2.9	0.25 – 2.25	< 0.05	< 0.05	2.1 –10.5	65.3 – 288	0.5 – 3.1	< 0.1	< 0.15 –1.9	19.8 - 59.0	<0.15 – 11.8	13.9 – 25.2	0.65 – 8.8	10.8 – 27.6
Avg ± SD	1.3 ± 1.1	1.6 ± 1.1	1.54 ± 0.85	< 0.05	< 0.05	4.7 ± 3.9	199 ± 76.0	1.8 ± 1.1	< 0.1	0.5 ± 0.9	40.7 ± 15.3	4.2 ± 6.6	20.2 ± 4.9	3.0 ± 3.8	19.2 ± 6.5
WATER QUALITY STANDARD															
WQCA	–	1000	–	5	–	50	–	10	–	50	–	–	–	–	–
WQCH	–	2000	–	5	–	50	–	10	–	50	–	–	–	–	–

Remarks

RHg = reactive mercury (inorganic mercury)

THg = total mercury (all form of dissolved mercury)

Concentration unit of heavy metals in particulate matter is on dry weight basis

Table 3-4: Range (minimum – maximum) and average (± s.d.) of dissolved and particulate heavy metals in Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Hg			Cd		Pb		As		Cr		Ni		Cu	
	D-RHg (ng/L)	D-T Hg (ng/L)	P-Hg (mg/kg)	D-Cd (µg/L)	P-Cd (mg/kg)	D-Pb (g/L)	P-Pb (mg/kg)	D-As (µg/L)	P-As (mg/kg)	D-Cr (µg/L)	P-Cr (mg/kg)	D-Ni (µg/L)	P-Ni (mg/kg)	D-Cu (µg/L)	P-Cu (mg/kg)
THIS STUDY															
Mekong River Section 1															
Min – Max	0.07 – 0.8	0.4 – 1.6	< 0.10 – 1.42	< 0.005	< 0.05	0.2–10.5	65.3 – 182	< 0.3 – 5.5	< 0.1	<0.15 – 1.9	23.7 – 59.0	<0.15 –11.8	8.0 – 25.2	< 0.15 – 8.7	9.8 – 19.4
Avg ± SD	0.4 ± 0.3	0.9 ± 0.4	0.46 ± 0.48	< 0.005	< 0.05	3.9 ± 3.08	114 ± 41.2	3.2 ± 1.6	< 0.1	0.7 ± 0.7	36.4 ± 12.9	2.2 ± 3.9	12.4 ± 5.8	3 ± 2.7	13.6 ± 4.0
Mekong River Section 2															
Min – Max	0.37 – 2.8	0.8 – 2.9	< 0.10 – 2.24	< 0.005	< 0.05	0.25 – 3.05	94.6 – 230	< 0.3 –1.5	< 0.1	<0.15 – 0.20	19.8 – 53.5	<0.15 – 1.3	0.05 – 22.5	< 0.15 – 1.45	8.7 – 28.1
Avg ± SD	1.1 ± 1.1	1.48 ± 1.01	0.83 ± 0.95	< 0.005	< 0.05	1.6 ± 1.2	189 ± 63.4	0.7 ± 0.6	< 0.1	0.1 ± 0.06	36.7 ± 17.1	0.9 ± 0.4	12.8 ± 10.2	1.2 ± 0.4	19.8 ± 9.6
Mekong River Section 3															
Min – Max	0.32 – 4.72	0.6 – 6.2	< 0.10 – 2.56	< 0.005	< 0.05	0.4 – 3.16	169 – 293	< 0.3 – 2.5	< 0.1	<0.15 – 0.58	20.9 – 48.7	<0.15 – 1.68	3.5 – 23.4	0.7 – 2.8	15.3 – 26.9
Avg ± SD	1.7 ±1.4	2.3 ±1.7	1.30 ± 0.31	< 0.005	< 0.05	1.4 ± 0.9	233 ± 38.8	1.3 ± 0.9	< 0.1	0.2 ± 0.2	34.0 ± 10.9	0.5 ± 0.6	12.9 ± 7.0	1.4 ± 0.7	20.7 ± 3.8
Tonle Sap															
Min – Max	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Avg ± SD	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
WATER QUALITY STANDARD															
WQCA	–	1000	–	5	–	50	–	10	–	50	–	–	–	–	–
WQCH	–	2000	–	5	–	50	–	10	–	50	–	–	–	–	–

Remarks
Section 1 = Stations 1 to 9 (9 Stations)
Section 2 = Stations 10 to 17 (8 Stations)
Section 3 = Stations 18, 21 to 28 (9 Stations)
Section 4 = Stations19 and 20 (2 Stations)

Since the heavy metals labile fraction was not measured in this study, a partitioning coefficient was computed by dividing the total particulate heavy metal concentration (residual fraction = labile + residual) by the total dissolved metals. The partitioning coefficients (values shown are log K_d values) of heavy metals in surface water of the LMB calculated for all stations are presented in Table 3-5. Figure 3-18 shows the plots of log K_d versus stations with distance in the mainstream.

A review of K_d values has been conducted by the US.EPA (Allison and Allison, 2005), where K_d values were obtained from a literature search for various metals for some 166 different sites. This study used statistical models, geochemical modelling and expert judgement to establish a reasonable range and/or median value for the partitioning coefficient for all metals in all media-types. For suspended matter over the dissolved species in water, the K_d of Hg, Cd, Pb, As, Cr, Ni and Cu retrieved from US.EPA compilation are presented in Table 3-6.

3.1.2.1 Mercury

Although the threshold value of WQCH and WQCA are set at 1.0 and 2.0 µg/L, dissolved mercury in natural water is extremely low with a level of sub-nanogram per litre (ng/L). Determination of Hg in sub-nanogram per litre levels requires a very high sensitive gold amalgamate pre-concentration technique in conjunction with cold vapour atomic fluorescence detection.

Table 3-5: The portioning coefficients (log K_d) calculated for all stations obtained in the Lower Mekong Basin from dividing the average of particulate metal concentration (mol/kg) by the value of total dissolved metals (mol/L).

(a) All stations

Station Name	CODE	Log K_d Hg	Cd	Pb	As	Cr	Ni	Cu
1. Houa Khong	LMH	6.12	–	5.06	–	–	4.82	4.28
2. Sob Rouak	TSR	5.44	–	4.46	–	4.62	3.99	3.64
3. Chiang Sean	TMC	6.10	–	4.27	–	4.59	4.00	3.54
4. Kok River Mouth	TKR	–	–	3.79	–	4.50	3.33	3.09
5. Chiang Khong	TCK	–	–	4.28	–	4.10	3.72	3.49
6. Luang Prabang	LPB	–	–	4.56	–	5.17	4.01	3.67
7. Vientiane	LVT	5.74	–	4.58	–	4.62	4.43	3.92
8. Nakhon Phanom	TNP	5.98	–	5.96	–	–	–	–
9. Xe Bang Fai	LFB	No sample						
10. Kong Chiam	TMM	5.87	–	4.84	–	–	–	4.36
11. Pakse	LPS	5.47	–	5.96	–	–	4.24	4.39
12. Strung Treng	CMR	–	–	4.79	–	5.09	4.16	3.81
13. Siem Pang	CKM	No sample						
14. Adoung Meas	CSS	No sample						
15. Lumpat	CSP	No sample						
16. Sekong River Mouth	CSR	No sample						
17. Kratie	CKT	5.48	–	5.18	–	–	4.24	4.28
18. Chrouy Changvar	CCV	5.81	–	4.82	–	4.81	4.08	3.89
19. Bak Prea	CBP	No sample						
20. Phnom Krom	CCK	No sample						
21. Prek Kdam	CTU	6.43	–	5.06	–	–	4.69	4.13
22. Phnom Penh Port	CPP	5.92	–	4.96	–	–	–	4.31
23. Nak Loeung	CNL	4.22	–	5.19	–	4.91	4.07	3.85
24. Koh Khel	CKL	5.69	–	5.36	–	–	–	4.37
25. Chau Doc	VCD	6.31	–	5.64	–	–	–	4.48
26. Tan Chau	VTC	5.75	–	5.39	–	–	4.36	4.12
27. Can Tho	VCT	5.94	–	5.77	–	–	4.18	4.28
28. My Thuan	VTR	–	–	5.51	–	4.88	4.40	4.31

(b) Range (minimum – maximum) and average

Metal		Mainstream & Tributaries: Mainstream	Tributaries	River Sections: Section 1	Section 2	Tonle Sap	Section 3
Hg	Min – Max	4.22 – 6.31	5.87 – 6.43	5.44 – 6.12	5.47 – 5.87	No sample	4.22 – 6.43
	Avg ± SD	5.70 ± 0.50	6.08 ± 0.83	5.87 ± 0.26	5.61 ± 0.19		5.76 ± 0.63
Cd	Min – Max	–	–	–	–	No sample	–
	Avg ± SD						
Pb	Min – Max	4.27 – 5.96	3.79 – 5.06	3.79 – 5.96	4.79 – 5.96	No sample	4.82 – 5.77
	Avg ± SD	5.10 ± 0.55	4.66 ± 0.31	4.62 ± 0.61	5.19 ± 0.47		5.30 ± 0.30
As	Min – Max	–	–	–	–	No sample	–
	Avg ± SD						
Cr	Min – Max	4.10 – 5.17	4.50	4.10 – 5.17	5.09	No sample	4.81 – 4.91
	Avg ± SD	4.77 ± 0.32		4.60 ± 0.34			4.86 ± 0.04
Ni	Min – Max	3.72 – 4.82	3.33 – 4.69	3.33 – 4.82	4.16 – 4.24	No sample	4.07 – 4.69
	Avg ± SD	4.19 ± 0.25	4.01 ± 0.49	4.04 ± 0.44	4.22 ± 0.04		4.30 ± 0.22
Cu	Min – Max	3.49 – 4.48	3.09 – 4.36	3.09 – 4.28	3.81 – 4.39	No sample	3.85 – 4.48
	Avg ± SD	4.02 ± 0.32	3.97 ± 0.35	3.66 ± 0.34	4.21 ± 0.24		4.19 ± 0.20

Table 3-6: The portioning coefficients (log K_d) calculated for all stations obtained in the Lower Mekong Basin from dividing the average of particulate metal concentration (mol/kg) by the value of total dissolved metals (mol/L).

(a) US-EPA compilation[(a)]

Metals	log K_d (L/kg)			
	Median	Average ± SD	Min - Max	N
Hg (II)	5.3	5.3 ± 0.4	4.2 – 6.9	26
Methyl Hg	–	4.9 ± 0.7	4.2 – 6.2	Model results
Cd (II)	5.0	4.9 ± 0.6	2.8 – 6.3	38
Pb (II)	5.7	5.7 ± 0.4	3.4 – 6.5	38
As	4.0	3.9 ± 0.5	2.0 – 6.0	25
Cr (III)	5.1	5.1 ± 0.4	3.9 – 6.0	25
Cr (VI)	–	4.2 ± 0.5	3.6 – 5.1	Model results
Ni (II)	4.3	4.4 ± 0.4	3.5 – 5.7	25
Cu (II)	4.7	4.7 ± 0.4	3.1 – 6.1	42

(b) Other studies

Metals	log K_d (L/kg)			
	Gediz River[(b)] (Turkey) (average)	Lake Balaton[(c)] (Hungary) range)	Po River[(d)] (Italy) (range)	Capivara Reservoir[(e)] (Brazil) (average ± SD)
Cd	not determined	4.6 – 5.8		3.80 ± 0.78
Pb	3.27	5.6 – 6.4	5.3 – 5.7	4.49 ± 0.42
Cr			4.8 – 5.2	6.98 ± 0.41
Ni	1.93	3.3 – 5.0	4.0 – 5.0	5.60 ± 0.66
Cu	1.96	4.0 – 5.7	4.5 – 5.2	5.86 ± 0.41

(a) Allison and Allison (2005)
(b) Kucuksezgin et al. (2008)
(c) Nguyen et al. (2005)
(d) Davide et al. (2003)
(e) Barreto et al. (2011)

The concentration of total dissolved mercury (T-Hg) in surface water of the LMB ranged from 0.4 to 6.1 ng/L (average 1.6 ± 1.4 ng/L) and from 0.8 to 2.9 ng/L (average of 1.6 ± 1.1 ng/L) in the mainstream and tributaries, respectively (Table 3-3). Comparisons of reactive mercury (R-Hg), total mercury (T-Hg) and particulate mercury (P-Hg) in surface water of the LMB are shown in Figures 3-12a (mainstream and tributaries) and 3-12b (Mekong River sections). In general, all mercury species (R-Hg, T-Hg and P-Hg) increase as you move downstream.

With regard to the partitioning coefficients, the K_d values of all stations were higher than 5.4 (Table 3-5a). Only one sample, from Neak Loung (CNL) station, has a low K_d at 4.2 L/kg. Slightly higher K_d values were found in the tributaries than in the mainstream (Table 3-5). In comparison, moving downstream in the mainstream Mekong River, the K_d values range from 4.2 to 6.3 L/kg with an average of 5.7 ± 0.5 L/kg (Table 3-5b), and show a scattering pattern (Figure 3-18). A slightly higher average K_d in the Mekong River than the average K_d reviewed by US.EPA in Table 3-6(a) indicates a slight preference for Hg to form stable complexes in the particulate phase in the Mekong River than in the other places (except CNL station). This may be due to an increased level of human activities causing pollution – namely port, industry and community – at this location.

3.1.2.2 Cadmium (Cd)

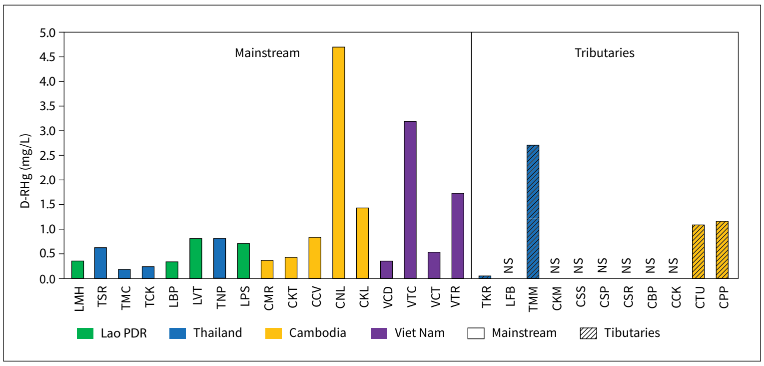
Cadmium is generally not thought to have a biological function or algal requirement in aquatic systems. It has a trace concentration (sub-microgram per litre) in natural water. In oxygenated water, Cd is present at equilibrium in the +2 oxidation state, whose chemistry can be considered in terms of complexation of the Cd2+ cation. The major species of Cd presented in low alkalinity river water is free hydrated Cd2+, while the major species in high alkalinity river water is complexed with inorganic ligand (carbonate) (Turner, 1987). According to Hart et al. (2001), the Mekong River is considered a low alkalinity river. However, it has noticeably higher alkalinity water in the upstream reaches around Vientiane (ca. 100 mg/L as HCO3, i.e. approx. 1.64 mequi/L) than in the downstream reaches below Kratie (ca. 60 mg/L, i.e. approx. 0.98 mequi/L).

In this study, the Cd concentration found is lower than the detection limit of the analytical method (< 0.005 μg/L for dissolved species and < 0.05 mg/kg for particulate bound species). Therefore, the concentration of Cd in the study area is far lower than the water quality standard (WQCA and WQCH) limit of 5 μg/L. The partitioning coefficient of Cd reported in Barreto et al. (2011) and other works is lower than other metals, indicating a preference to be in the soluble form rather than forming stable complexes in the particulate phase.

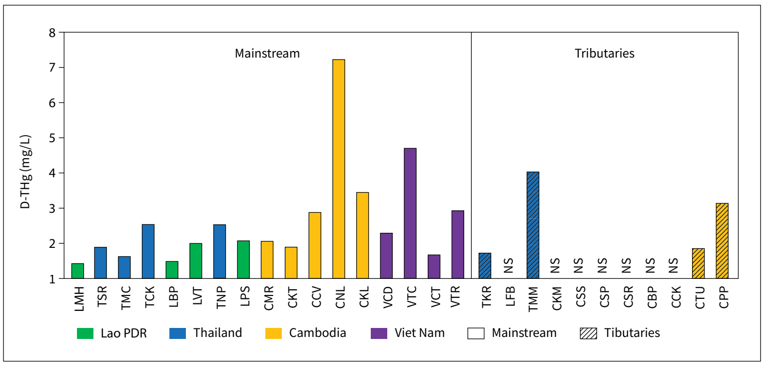
No other study can be used for comparison since there has been very little work to determine metal levels in the Mekong River. Cenci and Martin (2004), who worked in the Mekong delta in 1997 (salinity ranged from 0.02 to 33.6 in March and 0.05 to 31.5 in

Figure 3-12a: Comparison of dissolved and particulate Mercury (Hg) in surface water of mainstream and tributaries (The WQCA and WQCH thresholds for dissolved mercury are 1000 mg/L and 2000 mg/L, respectively).

Dissolved Reactive Mercury (R-Hg)



Dissolved Total Mercury (T-Hg)



Particulate Mercury

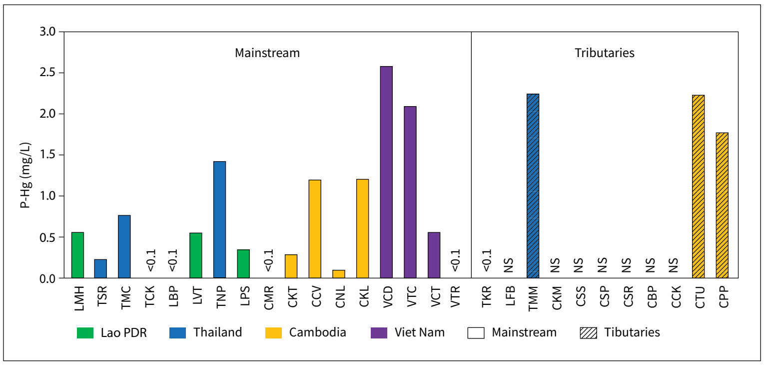
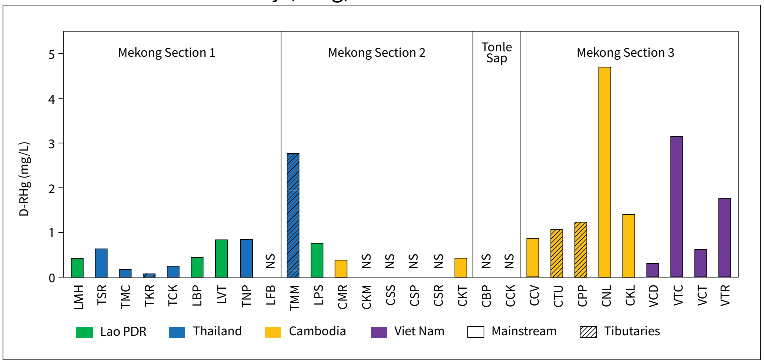
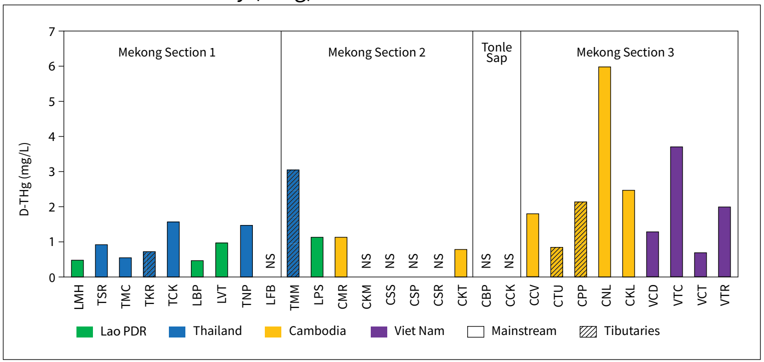


Figure 3-12b: Comparison of dissolved and particulate Mercury (Hg) in surface water of Mekong River Sections 1, 2, 3 and Tonle Sap (The WQCA and WQCH thresholds for dissolved mercury are 1000 ng/L and 2000 ng/L, respectively).

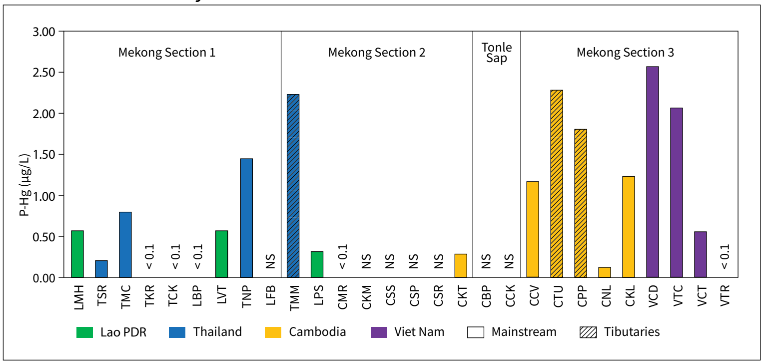
Dissolved Reactive Mercury (R-Hg)



Dissolved Total Mercury (T-Hg)



Particulate Mercury



October), reported concentration ranges of D-Cd in March and October of 0.001–0.024 and 0.002–0.051 µg/L, with an average of 0.003 and 0.01 µg/L, respectively. The P-Cd concentration was not in the detectable level. The most upstream station in their study was at Can Tho where river water is entirely different in each season. There was no significant difference for D-Cd concentration in the river and seawater of the Mekong Delta. Cadmium behaves in a conservative way and does not seem to be affected by estuarine mixing.

3.1.2.3 Lead (Pb)

For dissolved lead (D-Pb), none of the sample exceeds the threshold value for WQCH and WQCA (50 ug/L). The highest value was found at the tributary station (Kok River (TKR), 10.5 ug/L). This may be due to a desorption of dissolved weakly-bound Pb from the non-lattice held fraction of sediments to be re-suspended in the water column. A slightly higher D-Pb level was found at upstream than downstream stations (Figure 3-13), while particulate lead (P-Pb) was generally elevated downstream, especially in Section 3 of the river.

In comparison with the study by Cenci and Martin (2004) in the Mekong Delta, the average D-Pb in this study was more than 10 times higher, while P-Pb was about 3 times higher than that found at the river mouth. The concentrations of D-Pb at the Mekong Delta in March 1997 (0.03–0.14ug/L) and in October 1997 (0.01–0.16 ug/L), with an average of 0.11 and 0.10 ug/L, respectively. P-Pb was 9–123 and 7–76 mg/kg, with averages of

42 and 19 mg/kg, respectively.

Increasing K_d values downstream (Figure 3-18) reflect the enrichments observed for Pb concentration with a significant increase from landward to seaward. In comparison with other studies and areas (Tables 3-5 and 3-6), this study indicated a similar or only slight difference in K_d values.

3.1.2.4 Arsenic (As)

No D-As in the surface water samples in the LMB exceeds the threshold value for WQCH and WQCA (10 µg/L). Average concentrations in the mainstream and tributaries were similar (1.9 ± 1.7 and 1.8 ± 1.1 µg/L), respectively (Table 3-3). The D-As value was higher in the upstream section and dropped downstream (Figures 3-14a and 3-14b). Particulate As (P-As) in the LMB was all at a non-detectable level (< 0.1 µg/g).

In comparison, a study in the Bijing River, which is an important tributary of the Lancang River (Yi et al. 2012), found concentrations of As in the dry season from about 5 to 30 mg/L (D-As + P-As). The high values were found near Jinding mining area and gradually decreased as the distance from the mining area increased. Concentrations fell to about 6 mg/L before reaching the Lancang River.

For the Bijing River, it was interpreted that when transferring with water, part of the suspended solids might flocculate and settle down to the bottom to become sediments under different hydraulic and physiochemical effects. Conversely, with the change of

Figure 3-13a: Comparison of dissolved and particulate lead (Pb) in surface water of mainstream and tributaries (The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of lead, respectively).

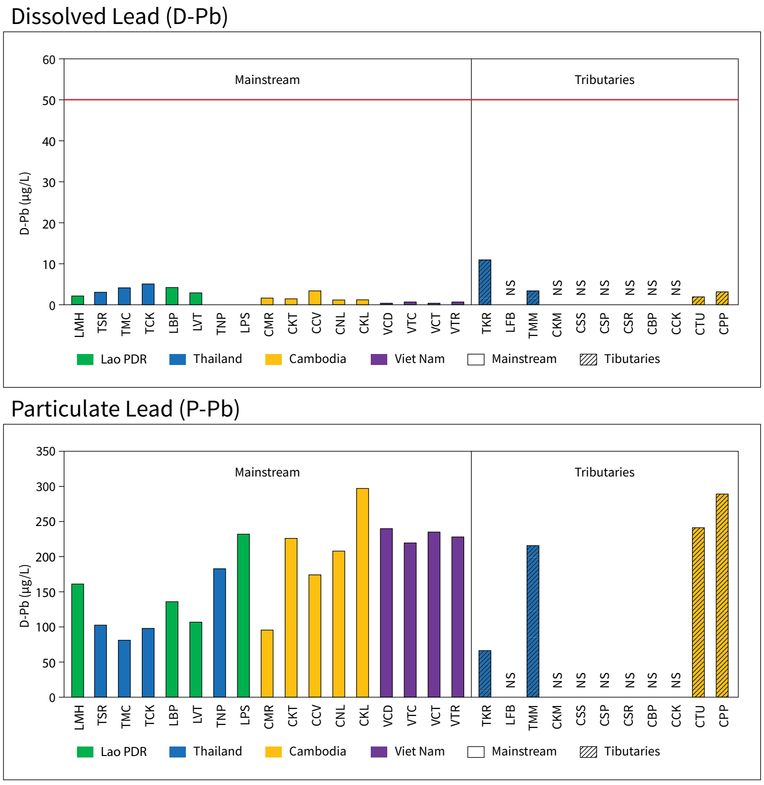


Figure 3-13b: Comparison of dissolved and particulate lead (Pb) in surface water of the Mekong River Sections 1, 2, 3 and Tonle Sap (The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of lead, respectively).

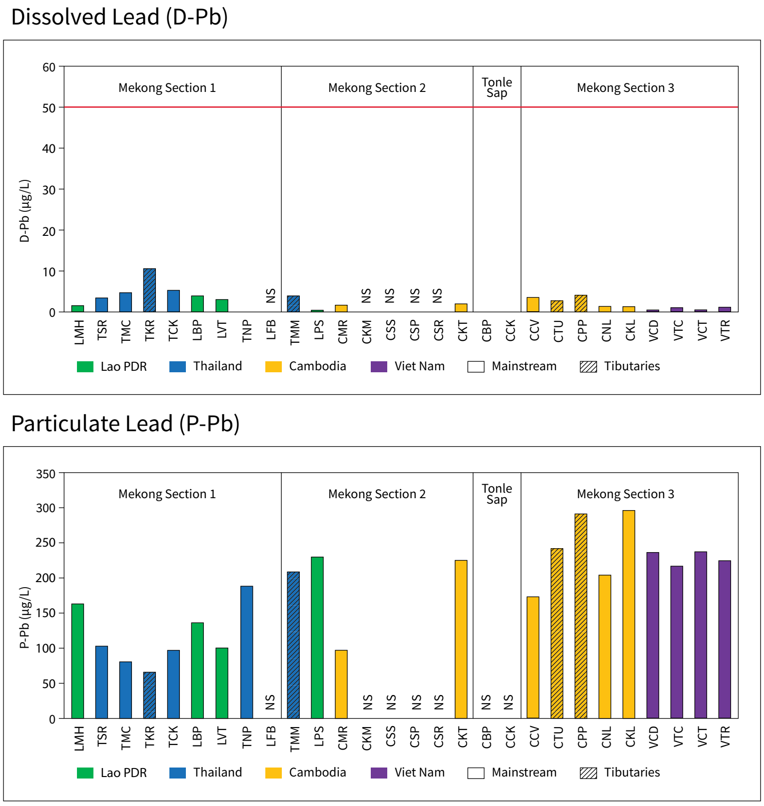


Figure 3-14a: Dissolved Arsenic in surface water of the mainstream and tributaries. The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of arsenic, respectively. (Note: Particulate Arsenic (As) in surface water of the Lower Mekong River and Its tributaries was at a non-detectable level).

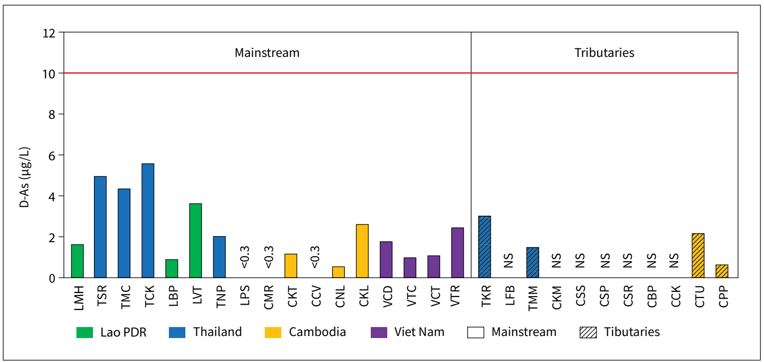
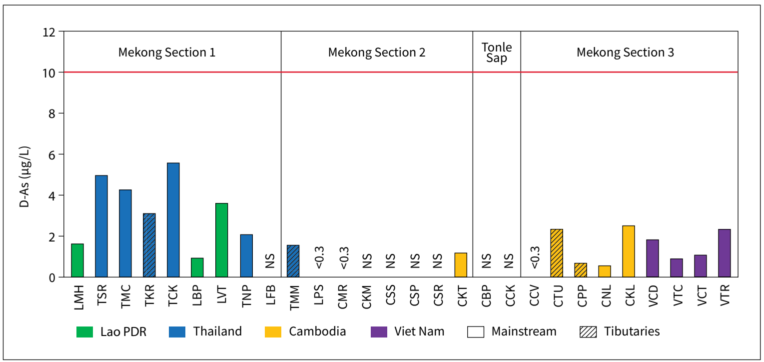


Figure 3-14b: Dissolved Arsenic in surface water of the Mekong River Sections 1, 2, 3 and Tonle Sap (The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of arsenic, respectively. (Note: Particulate Arsenic (As) in surface water of the lower Mekong River and its tributaries was at a non-detectable level).



environmental conditions (i.e. temperature, pH value and redox potential), the suspended solids and sediments might re-enter the water to create secondary pollution by means of dissolution, complexation and hydrolysis (Wang, 2008). Most of the arsenic was present as residue in the sediment, whose content was mainly affected by the As-containing pollutants discharged from stationary sources (Zhang and Xu, 2000), while those released from the sediments only constituted a small proportion of the total. Therefore, As concentration of the river water dropped most rapidly downstream of the mining area (Yi et al., 2012).

When comparing the survey reported here with studies in the Mekong Delta (Cenci and Martin, 2004; Ikemota, 2004), the level of P-As in this study (< 0.1 µg/g) was more than 10 times lower than those other studies. The P-As concentration reported by Cenci and Martin (2004) was 23.8 µg/g in March and 11 µg/g in October, and by Ikemota (2004) was 12 µg/g.

3.1.2.5 Chromium (Cr)

The concentration of dissolved chromium (D-Cr) in surface water of the LMB was fairly low in comparison to WQCA and WQCH thresholds of 50 µg/L (Figures 15a and 15b). There was no clear trend for P-Cr along the lower Mekong River section. The average concentrations of Cr in dissolved and particulate phases in all sections of the LMB were in a similar range (Tables 3-3 and 3-4). The level of P-Cr was also similar to previous studies in the estuarine section at the Mekong Delta, 49 µg/g in March and 29 µg/g in October (Cenci and Martin, 2004) and 18 µg/g (Ikemoto, 2004).

The K_d (L/kg) value of Cr was slightly elevated downstream, although the values are scattered (Table 3-5 and Figure 3-18). In comparison with other studies and areas (Tables 3-5 and 3-6), this study indicated a similar K_d of Cr as that reported for UA-EPA compilation (Allison and Allison, 2005) and Po River in Italy (Davide et al., 2003), but lower than for Capivara Resevoir in Brazil (Barreto et al., 2011) (Tables 3-5 and 3-6).

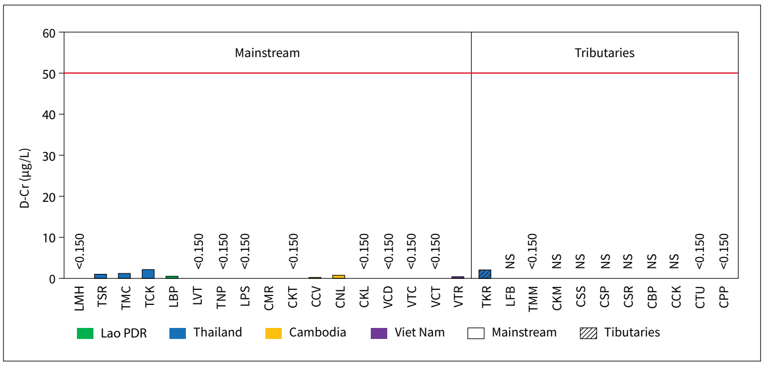
3.1.2.6 Nickel (Ni)

Average concentrations of D-Ni and P-Ni in the mainstream were 0.7 ± 0.6 µg/L and 11.9 ± 5.5 µg/g, respectively, and in the tributaries were 4.2 ± 6.6 µg/L and 20.2 ± 4.9 µg/g, respectively (Table 3-3). The high average value of D-Ni in the tributaries may not reflect a real situation of the tributaries because of only one sample from the Kok River mouth (TKR) station giving an obviously high D-Ni concentration when compared with all other samples (Figure 3-16a). However, it is also possible that nickel mobilised from particles at low salinity could be occurring, as reported in the Changjiang River (Edmond et al., 1985).

In comparison to the values found in the Mekong Delta, D-Ni in this study was slightly higher than the average 0.46 µg/L in March and 0.49 µg/L in October, while P-Ni was slightly lower than the average 32 µg/g in March and 18 µg/g in October reported by Cenci and Martin (2004). This is due to

Figure 3-15a: Comparison of dissolved and particulate Chromium (Cr) in surface water of mainstream and tributaries (The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of chromium, respectively).

Dissolved Chromium (D-Cr)



Particulate Chromium (P-Cr)

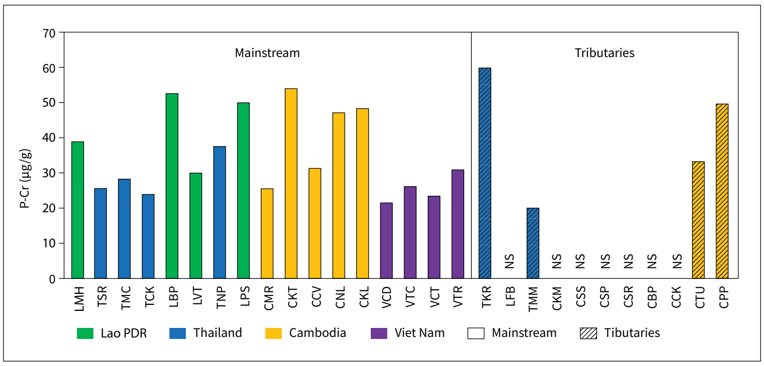
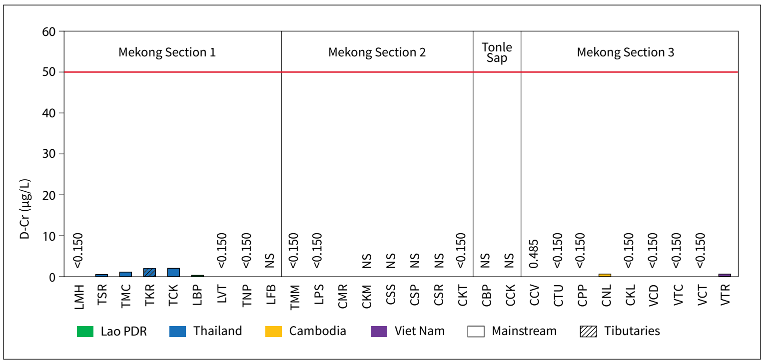


Figure 3-15b: Comparison of dissolved and particulate Chromium (Cr) in surface water of the Mekong River Sections 1, 2, 3 and Tonle Sap (The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of chromium, respectively.

Dissolved Chromium (D-Cr)



Particulate Chromium (P-Cr)

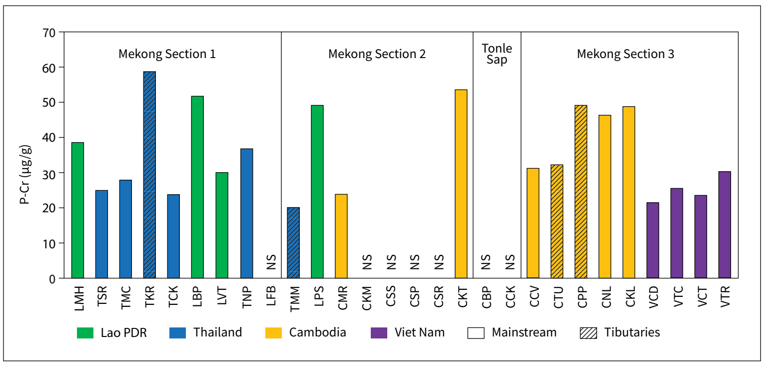
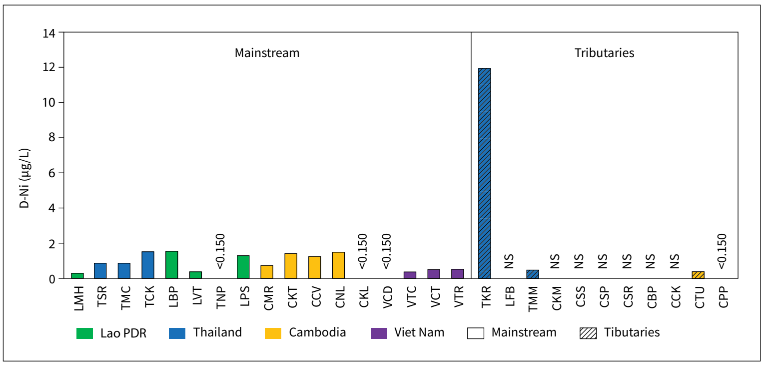


Figure 3-16a: Comparison of dissolved and particulate Nickel (Ni) in surface water of mainstream and tributaries (The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of nickel, respectively).

Dissolved Nickel (D-Ni)



Particulate Nickel (P-Ni)

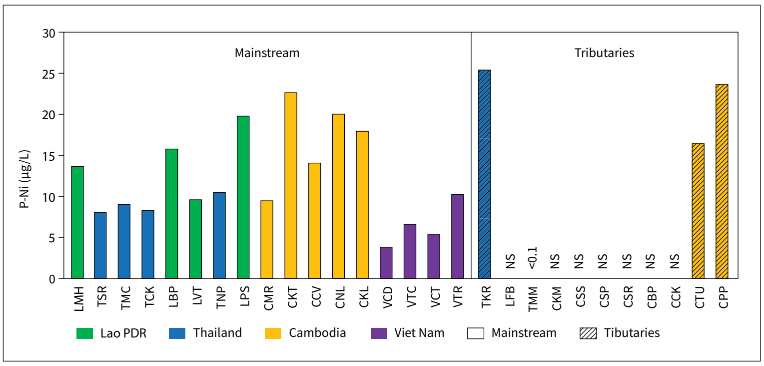
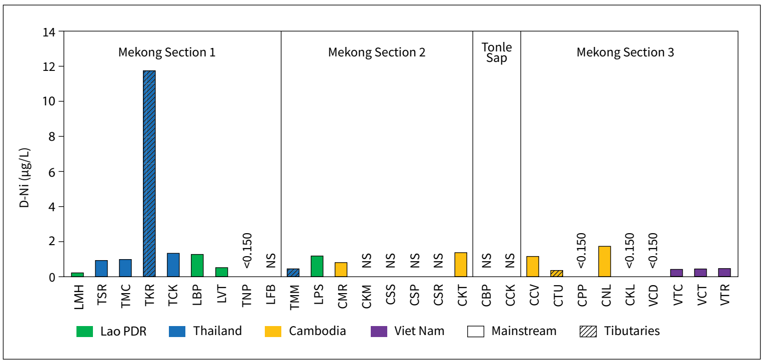
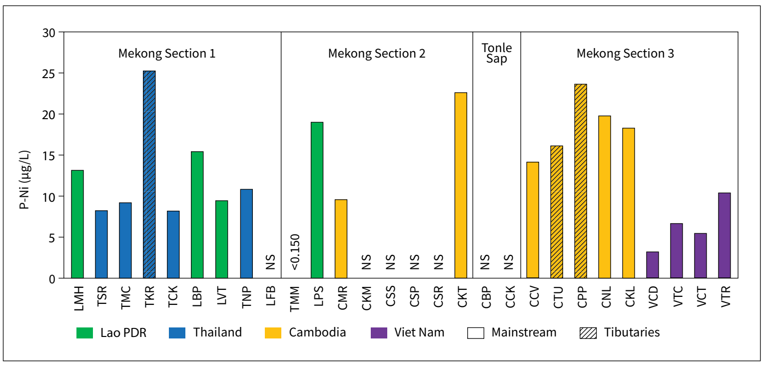


Figure 3-16b: Comparison of dissolved and particulate Nickel (Ni) in surface water of the Mekong River Sections 1, 2, 3 and Tonle Sap (The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of nickel, respectively).

Dissolved Nickel (D-Ni)



Particulate Nickel (P-Ni)



the scavenging by re-suspended solids or flocculating hydrated iron oxides and suggested to be responsible for metal removal in the low salinity zone of the estuaries (Windom et al., 1988).

With the exception of TKR, the K_d of Ni shows a clear increasing trend from upstream to downstream (Table 3-5 and Figure 3-18). This trend implies that the removal of D-Ni by adsorbing onto the particulate matter is higher in the downstream section.

In comparison with other studies and areas (Tables 3-5 and 3-6), this study indicated a similar K_d of Ni as reported for the US.EPA compilation (Allison and Allison, 2005), Lake Balaton in Hungary (Nguyen et al. 2005) and the Po River in Italy (Davide et al., 2003), but lower than that of the Capivara Resevoir in Brazil (Barreto et al., 2011) and higher than the Gediz River in Turkey (Kucuksezgin et al., 2008) (Tables 3-5 and 3-6).

With the exception of TKR, the K_d of Ni shows a clear increasing trend from upstream to downstream (Table 3-5 and Figure 3-18). This trend implies that the removal of D-Ni by adsorbing onto the particulate matter is higher in the downstream section.

In comparison with other studies and areas (Tables 3-5 and 3-6), this study indicated a similar K_d of Ni as reported for the US.EPA compilation (Allison and Allison, 2005), Lake Balaton in Hungary (Nguyen et al. 2005) and the Po River in Italy (Davide et al., 2003), but lower than that of the Capivara Resevoir in

Brazil (Barreto et al., 2011) and higher than the Gediz River in Turkey (Kucuksezgin et al., 2008) (Tables 3-5 and 3-6).

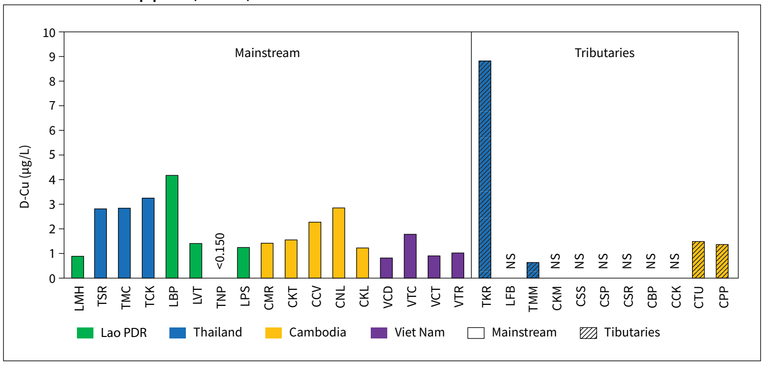
3.1.2.7 Copper (Cu)

It is generally known that copper is an essential element for biota. No WQCA and WQCH threshold values have been set. In this study, average concentrations of D-Cu and P-Cu in the mainstream were 1.7 ± 1.1 µg/L and 7.9 ± 6.2 µg/g, respectively and in the tributaries were 3.0 ± 3.8 µg/L and 19.2 ± 6.5 µg/g, respectively (Table 3-3). Similar to Ni, the high average value of D-Cu in the tributaries may not reflect a real situation of the tributaries because of only one sample from the Kok River mouth (TKR) station giving an obviously high D-Ni concentration compared to the other samples (Figure 3-16a). Distribution of D-Cu shows a declining trend moving downstream, in contrast to P-Cu, which shows an increasing trend toward downstream (Figure 3-17a). Cenci and Martin (2005) reported a lower concentration of D-Cu in the Mekong Delta (0.95 and 0.89 µg/L) in March and October, respectively, but no P-Cu value was reported.

The K_d values of Cu in the LMB watercourse obtained in this study show the smallest value of all the metals (Hg, Cd, Pb, As, Cr and Ni). This indicates that Cu tends to be in a more soluble form than other metals. With the exception of TKR, the K_d of Cu shows a clear increasing trend from upstream to downstream (Table 3-5 and Figure 3-18), indicating that the removal of D-Cu by adsorbing onto the particulate matter is higher in the downstream section.

Figure 3-17a: Comparison of dissolved and particulate Copper (Cu) in surface water of mainstream and tributaries (The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of copper, respectively).

Dissolved Copper (D-Cu)



Particulate Copper (P-Cu)

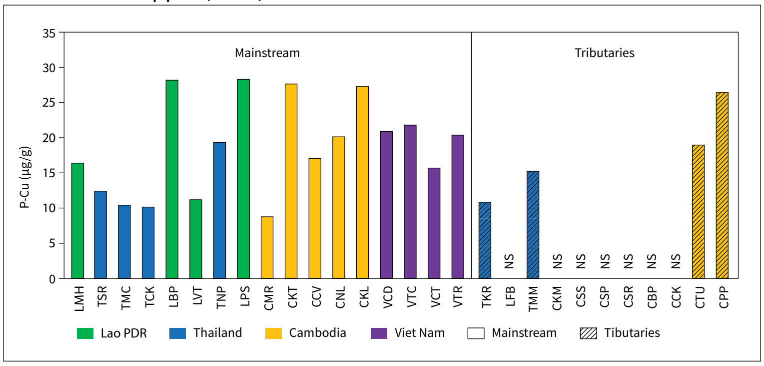
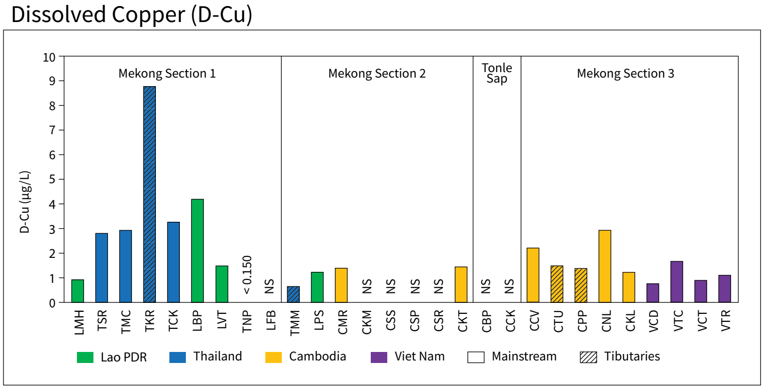


Figure 3-17b: Comparison of dissolved and particulate Copper (Cu) in surface water of the Mekong River Sections 1, 2, 3 and Tonle Sap (The red and blue horizontal lines indicate WQCA and WQCH thresholds for dissolved species of copper, respectively).

Dissolved Copper (D-Cu)



Particulate Copper (P-Cu)

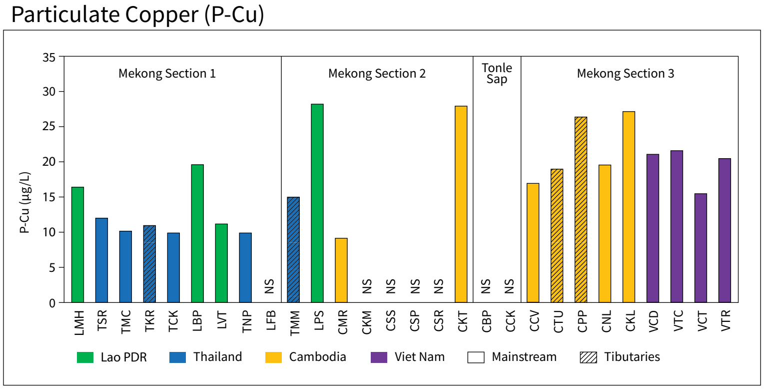


Figure 3-18: Plot of partitioning coefficients (log K_d in L/kg), from landward to seaward, obtained at 17 stations in the lower Mekong mainstream for mercury (Hg), lead (Pb), chromium (Cr), nickel (Ni) and copper (Cu).

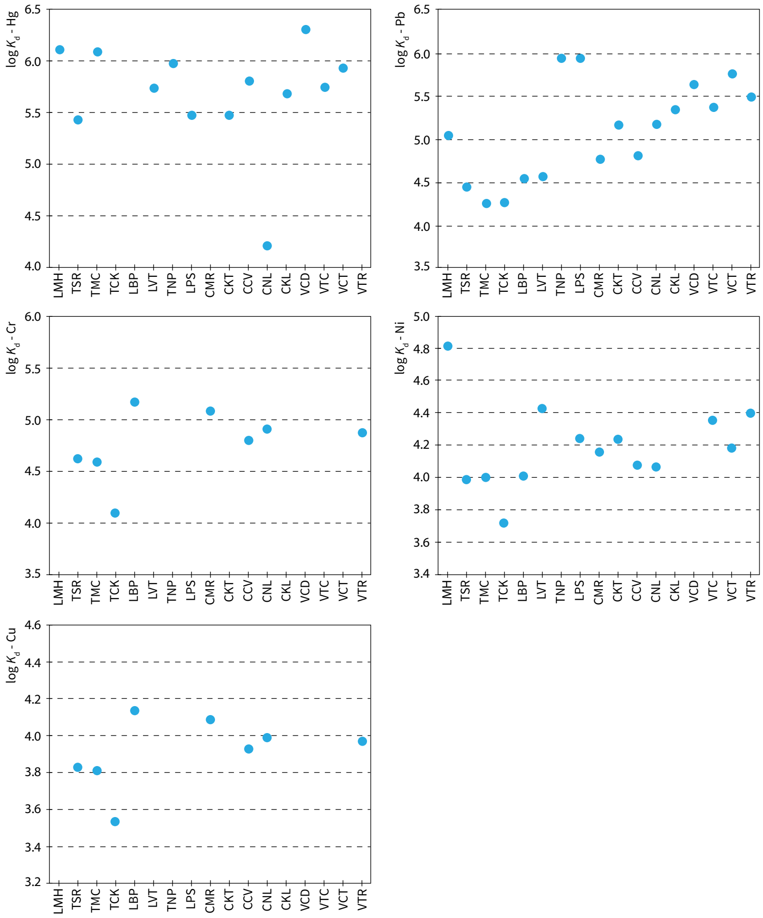
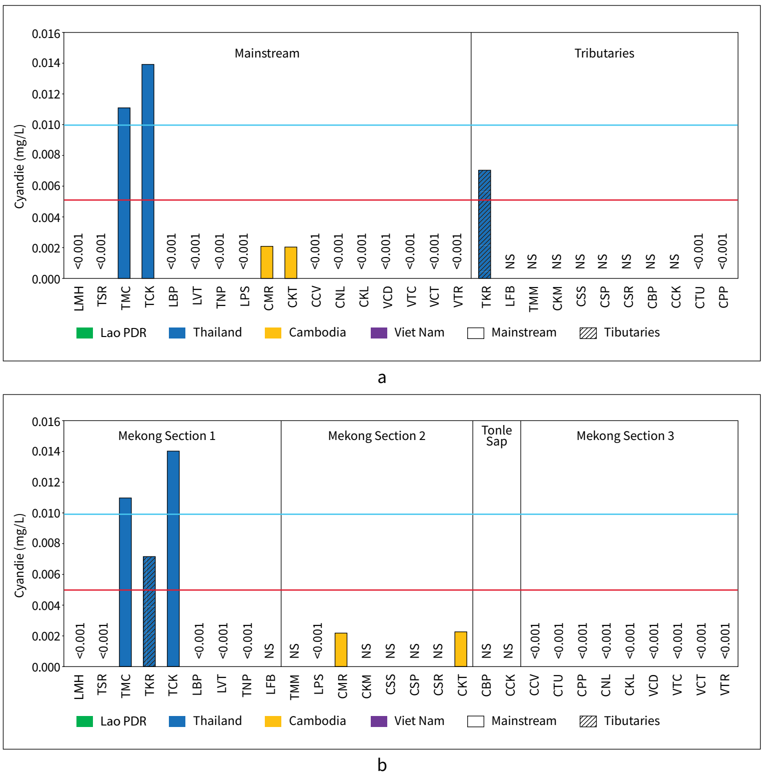


Figure 3-19: Comparison of cyanide in (a) mainstream and tributaries and (b)Mekong River Sections 1, 2, and 3 (The red and blue horizontal lines indicate WQCA and WQCH thresholds, respectively).



In comparison with other studies and areas (Tables 3-5 and 3-6), this study indicated a similar K_d of Cu as reported for the US.EPA compilation (Allison and Allison, 2005), Lake Balaton in Hungary (Nguyen et al., 2005) and the Po River in Italy (Davide et al., 2003), but lower than for Capivara Resevoir in Brazil (Barreto et al., 2011) and higher than for the Gediz River in Turkey (Kucuksezgin et al., 2008) (Tables 3-5 and 3-6).

3.1.3 ORGANIC MICRO-POLLUTANTS

Concentrations of organic micro pollutants in the Mekong River are presented in Tables 3-7 and 3-8. The 12 compounds of organic micro pollutants and groups dissolved in surface water of the Mekong are extremely low and below the detection limits of the method using in this study. (Tables 3-7 and 3-8). This indicates an unpolluted status of water for these organic micro pollutants. It is well understood that organic micro pollutants are hydrophobic and tend to be absorbed to particulate phases. This study once again confirms their fate and behaviour in river water.

Only two groups of organic micro pollutants; cyanide and phenols are detected in this study. Cyanide and phenol concentrations are presented in Figures 3-19 and 3-20.

3.1.3.1 Cyanides

As shown in Figure 3-19(a), cyanide concentrations in most of the mainstream and tributary stations are below detection limit of 0.001 mg/L, and therefore, are well below the WQCH and WQCA thresholds of 0.01 and 0.005 mg/L, respectively. During the

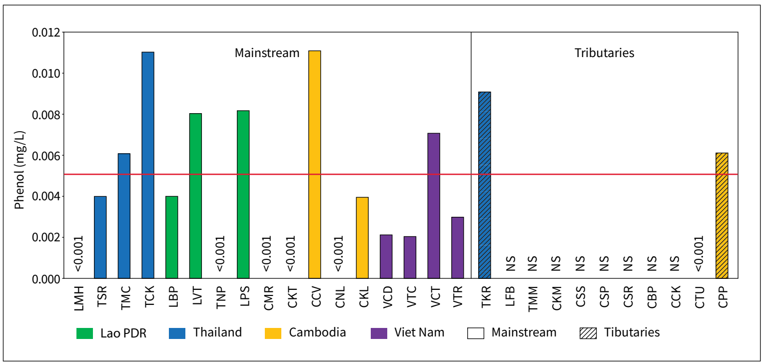
Table 3-7: Range (minimum – maximum) and average (± s.d) of dissolved phase organic micro pollutants in the Mekong River mainstream and tributaries.

Parameter	Total PCB (µg/L)	Hexachloro benzene (HCB)(µg/L)	Total Organochlorine Pesticide										Toxic Substances	
			p p' -DDT (µg/L)	p p' -DDE (µg/L)	p p' -DDD (µg/L)	Endrin Aldehyde (µg/L)	Endosulfan Sulfate (µg/L)	Heptachlor (µg/L)	Heptachlor Epoxide (µg/L)	α-Hexachloro Cyclohaxane (µg/L)	γ-Hexachloro Cyclohaxane (µg/L)	Chlordane (CHL) (µg/L)	Cyanide (CN) (mg/L)	Phenols (mg/L)
THIS STUDY Mekong River Mainstream														
Min – Max	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	<0.001-0.014	<0.001-0.011
Avg ± SD	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	0.0025±0.004	0.0044±0.003
Tributaries														
Min – Max	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	<0.001-0.007	<0.001-0.009
Avg ± SD	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	0.003±0.003	0.005±0.004
WATER QUALITY STANDARD														
WQCA	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005
WQCH	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.005

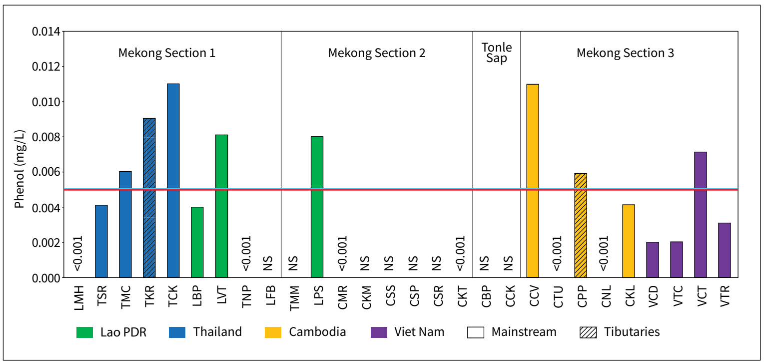
Table 3-8: Range Range (minimum – maximum) and average (± s.d) of dissolved phase organic micro pollutants in the Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Total PCB (µg/L)	Hexachloro benzene (HCB)(µg/L)	Total Organochlorine Pesticide										Toxic Substances	
			p p' -DDT (µg/L)	p p' -DDE (µg/L)	p p' -DDD (µg/L)	Endrin Aldehyde (µg/L)	Endosulfan Sulfate (µg/L)	Heptachlor (µg/L)	Heptachlor Epoxide (µg/L)	α-Hexachloro Cyclohaxane (µg/L)	γ-Hexachloro Cyclohaxane (µg/L)	Chlordane (CHL) (µg/L)	Cyanide (CN) (mg/L)	Phenols (mg/L)
THIS STUDY Mekong River Section 1														
Min – Max	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	<0.001-0.014	<0.001-0.011
Avg ± SD	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	0.005±0.005	0.006±0.004
Mekong Sub-basin 2														
Min – Max	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	<0.001-0.002	<0.001-0.008
Avg ± SD	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	0.002±0.001	0.003±0.004
Mekong Sub-basin 3														
Min – Max	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	<0.001	<0.001-0.011
Avg ± SD	<0.15	<0.02	<0.012	<0.008	<0.012	<0.012	<0.012	<0.004	<0.004	<0.004	<0.004	<0.1	<0.001	0.004±0.004
Tonle Sap														
Min – Max	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avg ± SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WATER QUALITY STANDARD														
WQCA													0.005	0.005
WQCH													0.01	0.005

Figure 3-20: Comparison of phenol in (a) mainstream and tributaries and (b) water in the Mekong River Sections 1, 2, 3 and Tonle Sap (The horizontal red and blue lines indicate WQCA and WQCH thresholds, respectively).



a



b

study, only three stations recorded cyanide concentrations exceeded the threshold. All three are located in Thailand. These high cyanide concentrations are likely to come from cyanide-containing pesticides, because the area contains plantations (orange orchards, tea plantations).

Mainstream and tributary stations showed similar average values of around 0.002 mg/L. Comparing results between sections (Figure 3-19b), the exceeded values are found in Section 1 while all stations in Section 3 are below the detection limit of 0.001 mg/L.

3.1.3.2 Phenol

Most mainstream and tributary stations are below the WQCH and WQCA threshold of 0.005 mg/L, while few stations exceed the threshold (Figure 3-20a and b). Phenol values found at Chiang Sean Pier 1 (TMC), Chiang Khong (TCK), Vientiane (LVT), Pakse (LPS) and Phnom Penh Port (CPP) exceeded the WQCA (0.005 mg/L) and WQCH (0.005 mg/L). Elevated values of phenols probably came from the use and possible leakage of petroleum products in some locations close to cities and navigation activities.

3.1.4 MULTIVARIABLE ANALYSIS OF WATER QUALITY DATA

Multivariable analysis of water quality data was treated by Hierarchical Cluster Analysis (HCA) and Principle Component Analysis (PCA) and was based on conventional parameter and heavy metal results. Therefore, only stations with a complete set of analysis were used (21 out of 28 stations). These include all mainstream stations and 4 stations in the tributaries, the latter being the Kok River mouth (TKR), Kong Chiam (TMM) and two stations in the Great Lake-Tonle Sap region – Prek Kdam (CTU) and Phnom Penh Port (CPP).

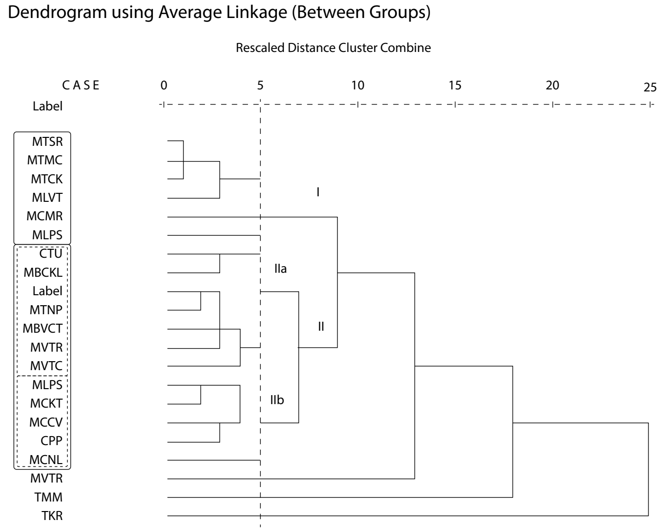
In this treatment, if the value is less than the detection limit, the average value is used (instead of the less than detection limit value). If one station is missing, that variable will be taken off automatically. Station names are indicated and categorised into 4 different sections of the LMB (upper, central, lower) and Tonle Sap with the following codes:

- B1-Station code Station on Mekong River Section 1 – upper part of the LMB (Stations 1–9)
- B2-Station code Station on Mekong River Section 2 – central part of the LMB (Stations 10–17)
- B3-Station code Station on Mekong River Section 3 – lower part of the LMB (Stations 18, 21–28).
- B4-Station code Station on Tonle Sap Sub-section (Stations 19–20).

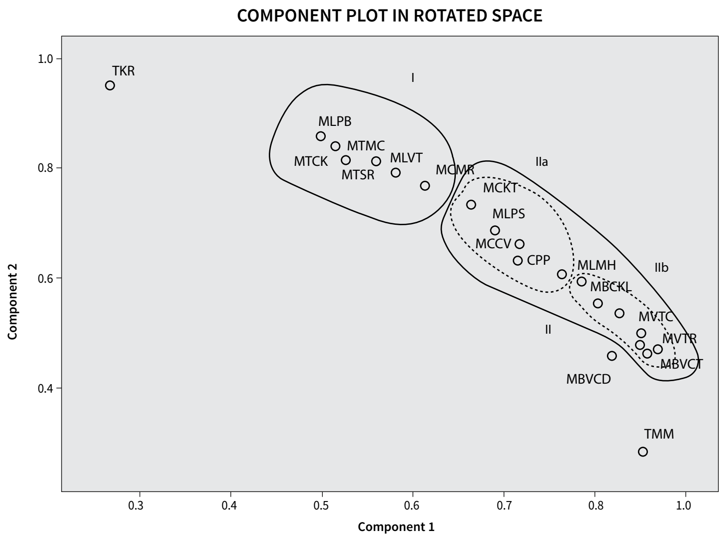
An HCA dendrogram and PCA loading score plot of the MMMAP water quality stations are shown in Figure 3-21. Apart from 3 stations (Kok River mouth (TKR), Kong Chiam (TMM) and Chau Doc (VCD), multivariate analysis can distinguish the sampling stations into 2 groups.

- The first group (group I) contains 6 stations: Sob Roak (TSR), Chiang Sean Pier (TMC), Chiang Khong (TCK), Vientiane (LVT), Stung Treng (CMR) and Luang

Figure 3-21: Multivariate analysis of all water quality variables for the MMMAP, (a) Hierarchical Cluster Analysis (HCA) dendrogram and (b) Principle Component Analysis (PCA) loading score plot.



a



b

Table 3-9: Rotated component matrix of conventional parameters in surface water.

(a) Rotated component matrix of conventional parameters in surface water

Variables	Component	
	1	2
BOD	-0.70	0.61
DO	0.61	0.23
Oil &Grease	0.36	0.22
Conductivity	-0.09	-0.33
SS	0.75	0.65
COD	0.32	0.70
Chlorophyll	-0.61	-0.09
TN	-0.21	-0.01
TP	0.01	-0.26
% Cumulative	**57.4**	**15.5**

(b) Rotated component matrix of heavy metal parameters in surface water

Variables	Component	
	1	2
Hg	0.71	-0.44
Pb	0.96	0.03
Cr	0.12	0.89
Ni	-0.05	0.99
Cu	0.88	0.36
% Cumulative	**57.0**	**32.4**

Prabang (LPB), which, apart from CMR, are located in the upper part of the LMB (sub-basin 1).

- The second group (group II) can be divided into 2 sub-groups:
  - Subgroup IIa consists of 7 stations: Houa Khong (LMH), Nakhon Phanom (TNP), Prek Kdam (CTU), Koh Khel (CKL), Can Tho (VCT), Tan Chau (VTC) and My Thuan (VTR). Most stations are located in the lower part of the LMB.
  - Subgroup IIb contains 5 stations: Phnom Penh Port (CPP), Pakse (LPS), Kratie (CKT), Chroy Changvar (CCV) and Neak Loung (CNL). Most stations are located in the central part of the LMB.

Apart from TKR and TMM, which are tributaries of the Mekong River, most sampling stations in group I are located in the upper part of Mekong River from (left to right Figure 3-21b) where there are less human activities to influence the river. Group II represents sampling stations in the middle and lower part of the LMB.

3.2 BOTTOM SEDIMENT

Sediments are the major store of contaminants and can be an important secondary source of pollutants, thus they are increasingly used to monitor aquatic environments. Sediments have been found to faithfully record and time-integrate the environmental status of an aquatic system, in contrast to water data which are dynamic and highly variable in the short term and which are difficult to interpret and costly to acquire (Birch et al., 2000a; 2000b).

However, the most important aspect regarding sediments is that they are the major carrier phase for pollutants and, because they integrate contaminants over time, sediments provide useful spatial and temporal information. Sediment quality largely influences the nature of the overlying water column and pore water through physical (re-suspension), chemical (benthic diffusion and desorption) and biological (bioturbation) processes. Sediments play an important role in identification of contaminant sources and determining dispersion pathways. They also provide an important habitat for benthic animals and are a food source for many pelagic and epibenthic species. Sediment quality thus determines, to a large degree, biodiversity and ecological health in aquatic systems. Sediments exhibit considerably less spatial and temporal variance in the field than biological systems (Birch, 2003).

Pollutants tend to be associated with the fine particles of marine sediments due to (i) the relative higher surface area, and (ii) the compositional characteristics of the fine particles. Both phyllosilicates (containing naturally lattice-held metal) and organic matter, which has chemical affinity for trace elements and organic pollutants, are concentrated in the clay (<2 μm) and fine silt (2–20 μm) fractions. Most other minerals, including feldspars and heavy minerals, are found in the fine and coarse (20–63 μm) silt fractions, whereas the sand fraction (63 μm – 2 mm) mainly consists of carbonate (calcite, aragonite, dolomite)

Figure 3-22: PCA loading score plot of MRC water sampling stations by region for (a) conventional parameters; (b) heavy metals.

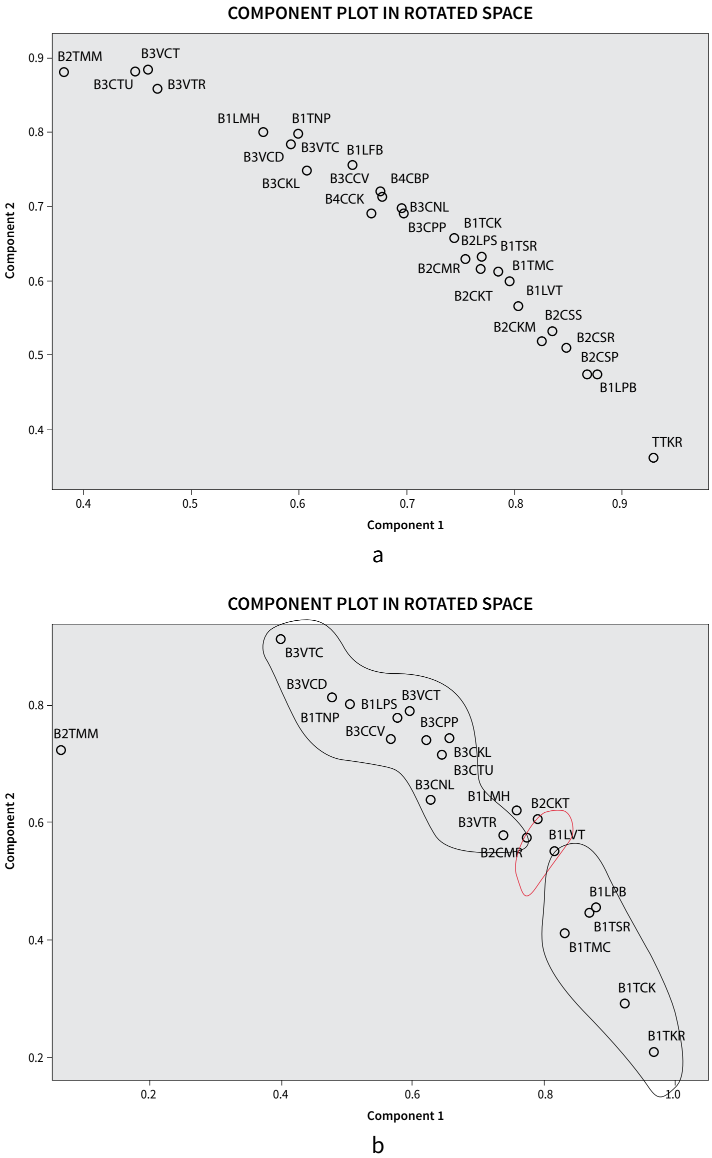
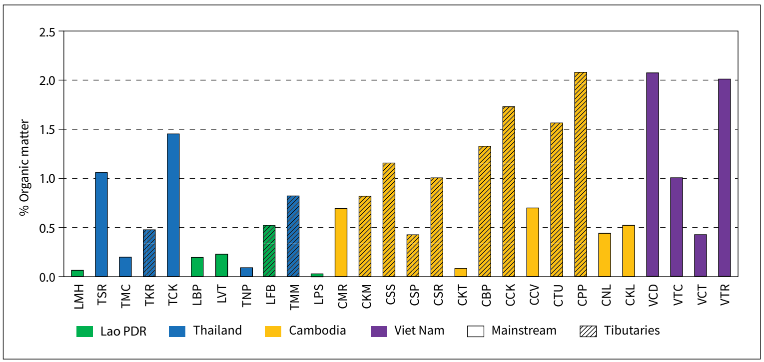


Figure 3-23: Organic matter content in Lower Mekong Basin sediment.



and/or silica (quartz, opal) minerals. In order to detect anomalous concentrations of anthropogenic origin it is necessary to normalize the results by a physical or a chemical factor (Loring and Rantala, 1992; Covelli and Fontolan, 1997; Herut and Sandler, 2006).

Chemical analyses of sediment are used for assessing the ability of sediment to support a healthy benthos (sediment quality) and for determining contaminant source and dispersion in aquatic systems. Total sediment analysis is used for sediment quality assessment, whereas source identification and dispersion require normalised contaminant data. Normalised contaminant data are obtained by physical fractionation (size-normalisation) of the sediment and analyses of a constant size fraction (usually the 62.5 µm fraction), whereas elemental normalisation uses the total sediment analysis normalised to a conservative element such as aluminium (Al) or Lithium (Li) (Birch, 2003). Thus, size and elemental normalisation techniques provide a clearer indication of source and dispersion than interpretation using analytical data directly.

Metal digestion using hydrofluoric acid (HF) was chosen to study heavy metal in the MMMAP study because it is the only acid that can dissolve all elements contained in the rock material, including Al which is used for normalisation (Loring and Rantala, 1992). The method was adopted by the UN Environment Programme (UNEP) in 1995 as the reference method for sediment studies.

3.2.1 SEDIMENT CHARACTERISTICS

Since the riverbed of the Mekong River is fairly heterogeneous, influenced by the high flow condition of the river, only analytical results of the composite samples are presented in this section.

Sediment quality results for the 27 Mekong River mainstream and tributary stations are presented. The percentage of organic matter accumulated in sediments is shown in Figure 3-23 and sediment texture is shown in Figure 3-24.

The organic matter content tends to be higher in tributaries and downstream stations (Figure 3-23) due to the lower flow velocity which allows the fine suspended solids to settle at the bottom of the stream. Bottom sediments in the upper and middle sections of the LMB were found to have low organic matter content; attributable to the low percentage of fine grain particles in sediments sampled (Figure 3-24). Fine sediment particles provide more surface area and higher chemical affinity to bind organic material.

The relationship between organic matter content and percentage of fine particles (< 63 µm) is shown in Figure 3-25. Sediment with finer particles tends to accumulate more organic material due to its larger surface area with high surface charge. The opposite is found in relation to the percentage of sand size particles (> 63 µm). The relationship with clay size particles in this study can't be seen clearly since the percentage of clay-size particles in most of the most samples was fairly low. A station containing higher organic matter and not following the trendline is My Thuan (VTR) station (Figure 3-25), suggesting a high accumulation of organic matter. However, because there is only one sample analysis in the area, the conclusion cannot be definite.

The highest organic matter values were found in sediments sampled from the Great Lake and Tonle Sap in Cambodia and the Mekong Delta in Viet Nam. As highlighted in Chapter 2, the rapid flow of the Mekong River mainstream and tributaries during the sampling period caused fine sediment accumulation to be reduced and sediment texture to be more variable across the river and along the river bank. In these circumstances, composite samples are considered to be more representative of conditions at each station.

3.2.2 HEAVY METALS

The concentration of heavy metals in bottom sediment along the Mekong River is

Figure 3-24: Sediment texture of Lower Mekong Basin sediments.

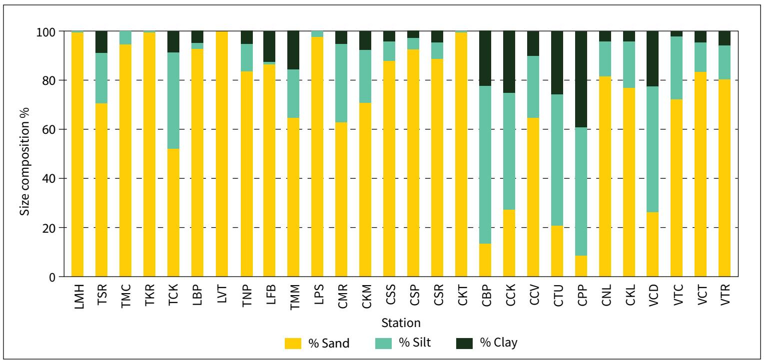


Figure 3-25: Relationship between organic content and percentage of fine grain (< 63 µm) particles in sediments.

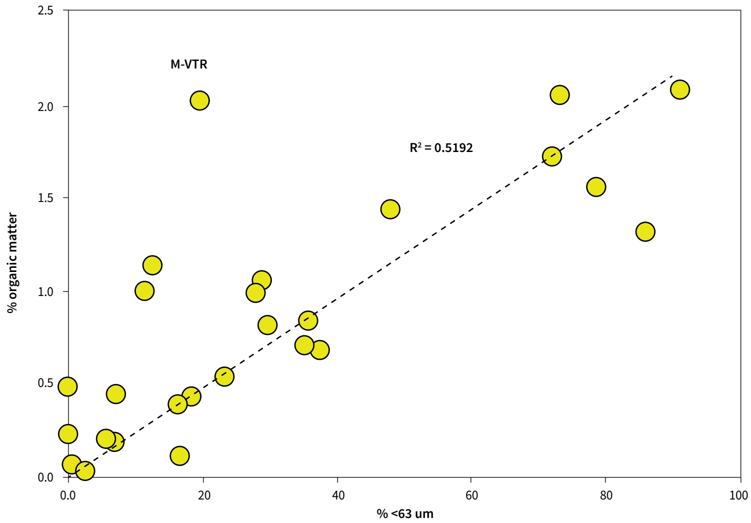


Table 3-10: Range (minimum – maximum) and average (± s.d.) of heavy metals in sediment in the Mekong River mainstream, tributaries and other studies.

Parameter	Hg (mg/kg)dry weight	Cd (mg/kg)dry weight	Pb (mg/kg) dry weight	As (mg/kg) dry weight	Cr (mg/kg) dry weight	Ni (mg/kg)dry weight	Cu (mg/kg) dry weight
THIS STUDY Mekong River Mainstream							
Min – Max	<0.1-0.320	<0.01	146-376	<0.1-1.33	15.4-58.0	6.61-21.40	5.47-26.50
Avg ± SD	0.120 ± 0.091	<0.01	208.1 ± 59	0.373±0.469	33.0±13.8	12.84±5.01	13.23±6.72
Tributaries							
Min – Max	<0.1-0.289	<0.01	122-293	<0.1-1.600	4.6-133.0	2.94-40.20	2.29-45.80
Avg ± SD	0.165 ± 0.088	<0.01	215 ± 52	0.575 ± 0.610	63.3 ± 42.2	22.27 ± 13.62	18.35 ± 13.74
OTHER STUDIES Mekong River Mainstream MRC (2007) (Diagnostic Year 2003 to 2004)							
Min – Max	<0.1	<0.1	<5 – 20	<5 – 15.1	6.2 – 52.7	<5 – 18.1	<5 – 18.1
Avg ± SD	–	–	10.4 ± 4.6	5.8 ± 4.7	13.9 ± 5.2	8.6 ± 4.8	5.4 ± 5.2
Tributary of Mekong River MRC (2007) (Diagnostic Year 2003 to 2004)							
Min – Max	<0.1	<0.1	<5 – 24	<5 – 7.7	22.5 – 48.8	<5 – 18.8	<5 – 24
Avg ± SD	–	–	14.2 ± 10.2	4.5 ± 2.5	34.1 ± 11.6	10.3 ± 6.6	11.2 ± 9.4
WATER QUALITY STANDARD							
ANZECC UPLAND	0.15	1.5	50	20	80	21	65
ANZECC LOWLAND	1.0	10	220	70	370	52	270

shown in Tables 3-10 and 3-11 and Figures 3-26 and 3-27. Heavy metal data from other studies is also provided as a comparison.

As the threshold level of heavy metals in sediment has not been specified in WQCH and WQCA, the ANZECC level for lowland and upland rivers was chosen and compared with this study.

Most heavy metals, except Pb, were far below the ANZECC lowland river threshold at all stations, while Hg, Cr and Ni concentration in sediment at some stations exceeded the ANZECC upland river threshold. Pb concentrations at all stations exceeded the ANZECC upland river threshold and, at some stations, also exceeded the ANZECC lowland river threshold.

The concentrations of mercury in sediment in both mainstream and tributaries and in the 4 Mekong River sections were in a similar range. As shown in Figure 3-26a, the exceeded Hg level found in this study were Sob Rouak (TSR), Chiang Khong (TCK), Andoung Meas (CSS) and Phnom Penh Port (CPP), due to an increase of human activities and community at these locations.

For Cr and Ni, the Cr concentration in this study ranged between 15.4–58 and 4.6-133 mg/kg in mainstream and tributaries, respectively (Table 3-10). Some stations exceeded the Cr and Ni ANZECC upland river threshold, namely Lumphat (CSP) and Chong Kanier (CCK) (Figures 3-26d and e). This may be caused by pollutant sources upstream as these locations were

Figure 3-26: Comparison of heavy metals in sediment in mainstream and tributaries (The horizontal red and blue lines indicate ANZECC upland and lowland river thresholds, respectively).

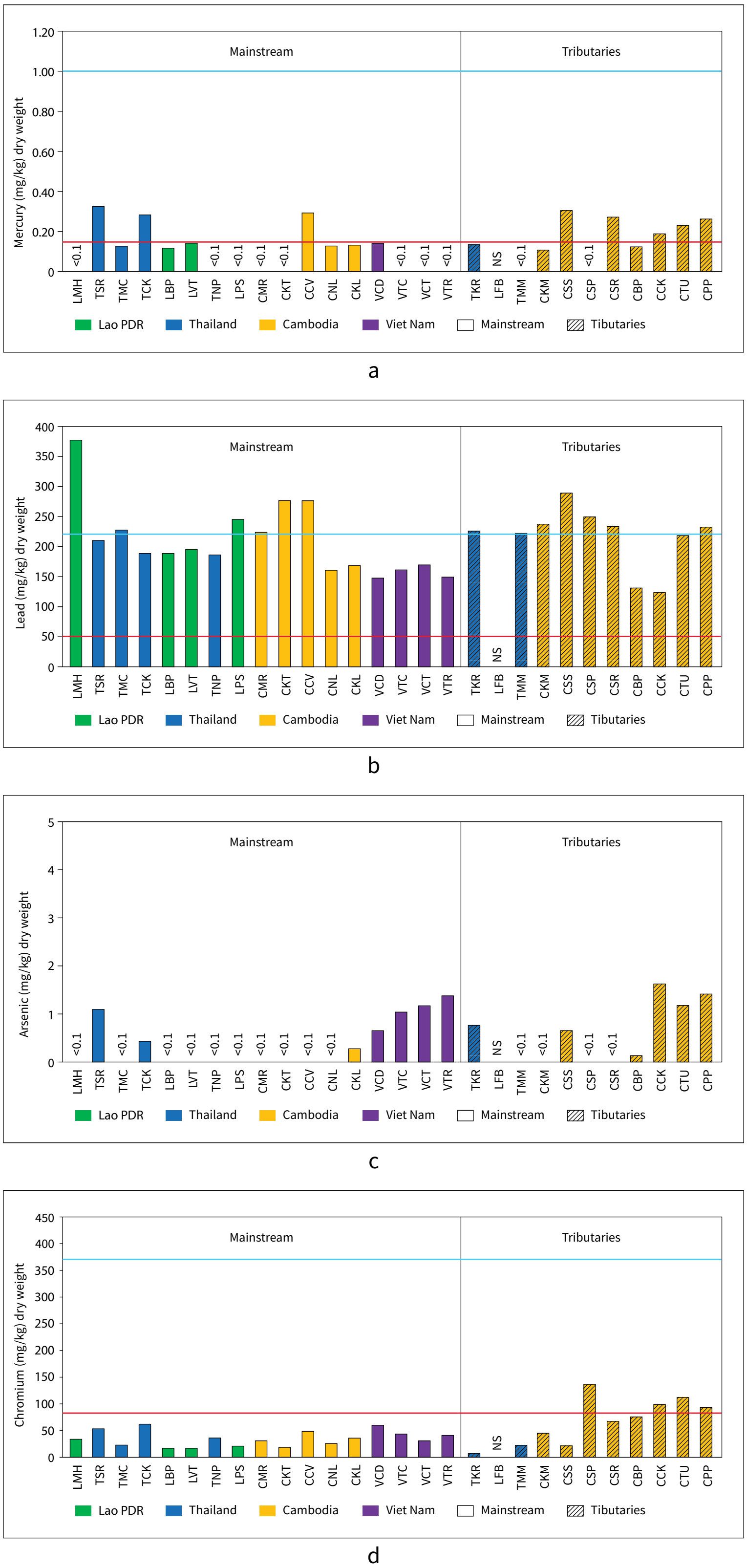


Table 3-11: Range (minimum – maximum) and average (± s.d) of heavy metals in sediment in the Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Hg (mg/kg) dry weight	Cd (mg/kg) dry weight	Pb (mg/kg) dry weight	As (mg/kg) dry weight	Cr (mg/kg) dry weight	Ni (mg/kg) dry weight	Cu (mg/kg) dry weight
THIS STUDY							
Mekong Section 1							
Min – Max	<0.1-0.320	<0.01	184-376	<0.1-1.040	4.58-56.80	2.94-20.2	2.29-26.50
Avg ± SD	0.152±0.100	<0.01	224±64	0.306±0.389	28.57±18.12	10.54±6.13	12.23±8.78
Mekong Section 2							
Min – Max	<0.1-0.289	<0.01	221-293	<0.1-0.605	17.90-133.00	6.50-29.20	6.30-18.9
Avg ± SD	0.111±0.100	<0.01	246±25	0.119±0.0.196	42.40±39.81	13.76±8.70	11.60±4.95
Mekong Section 3							
Min – Max	<0.1-0.275	<0.01	146-274	<0.1-1.36	24.6-104.0	11.20-40.20	9.21-45.80
Avg ± SD	0.144±0.090	<0.01	186±44	0.78±0.54	51.4±27.5	20.27±10.04	21.67±12.87
Tonle Sap							
Min – Max	0.116-0.175	<0.01	122-128	0.104-1.600	71.8-91.8	25.80-38.30	8.59-23.20
Avg ± SD	0.146±0.042	<0.01	125±4	0.852±1.058	81.8±14.1	32.05±8.84	15.90±10.33
SEDIMENT STANDARD							
ANZECC Upland River	0.15	1.5	50	20	80	21	65
ANZECC Lowland River	1.0	10	220	70	370	52	270

Remarks
Section 1 = Stations 1 to 9 (9 Stations)
Section 2 = Stations 10 to 17 (8 Stations)
Section 3 = Stations 18, 21 to 28 (9 Stations)
Section 4 = Stations19 and 20 (2 Stations)

characterised by small communities; with no dominant activities or pollutant sources.

For Pb, all 27 stations exceeded the ANZECC thresholds for both lowland and upland rivers. The Pb concentration ranges in this study are 146–376 and 122–293 mg/kg in the mainstream and tributaries respectively (Table 3-10 and Figure 3-26b). This indicated that Pb concentration needs to be further and closely monitored in the next monitoring program.

Sediment quality assessment, especially in terms of metal contamination, is very difficult and is prone to severe misinterpretations if the sediment's geochemical properties are not taken into account. At present, there are many methods proposed for assessing sediment quality. However, the difficulty is to define and use an appropriate "background value". Background may change from area to area within a region and between regions (Reimann and Garrett, 2005). Although global averages are of general use, there are no specific global background levels of elements. Practically, average metals in shale and crust taken from Turekian and Wedepohl (1961) and Taylor (1964) are generally chosen (Table 3-12). Using background estimates based on concentrations in deeper soil/sediment levels to judge element concentrations in upper soil/sediment horizons (e.g., the TOP/BOT-ratio) can lead to severe misinterpretations if natural biogeochemical soil formation processes are ignored. Because of large natural variations in element concentrations in, for example soil/sediment, even

Figure 3-26cont.: Comparison of heavy metals in sediment in mainstream and tributaries (The horizontal red and blue lines indicate ANZECC upland and lowland river thresholds, respectively).

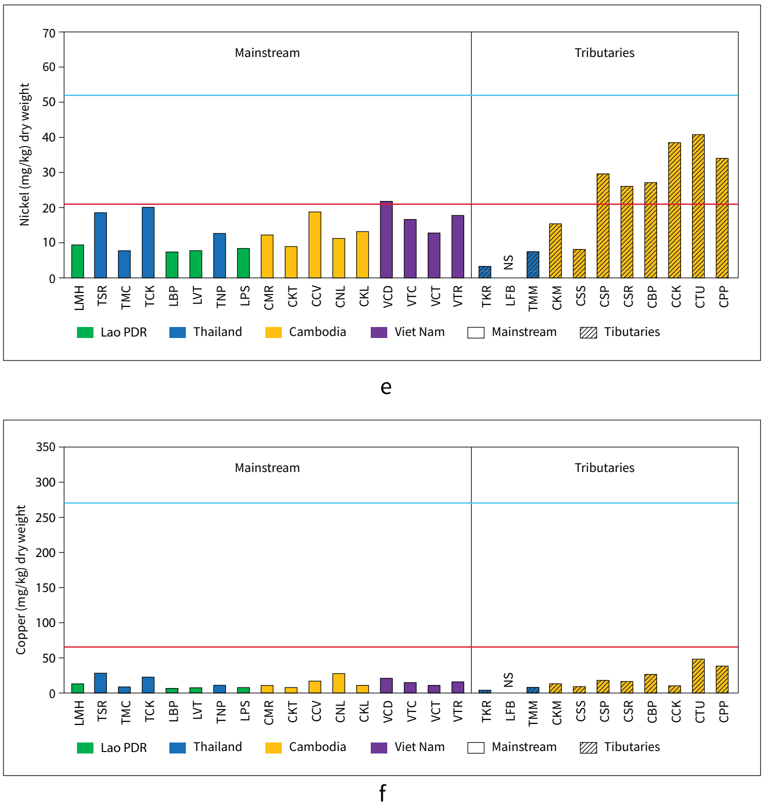


Figure 3-27: Comparison of heavy metals in sediment in Mekong River Sections 1, 2, 3 and Tonle Sap region (The horizontal red and blue lines indicate ANZECC upland and lowland river thresholds, respectively).

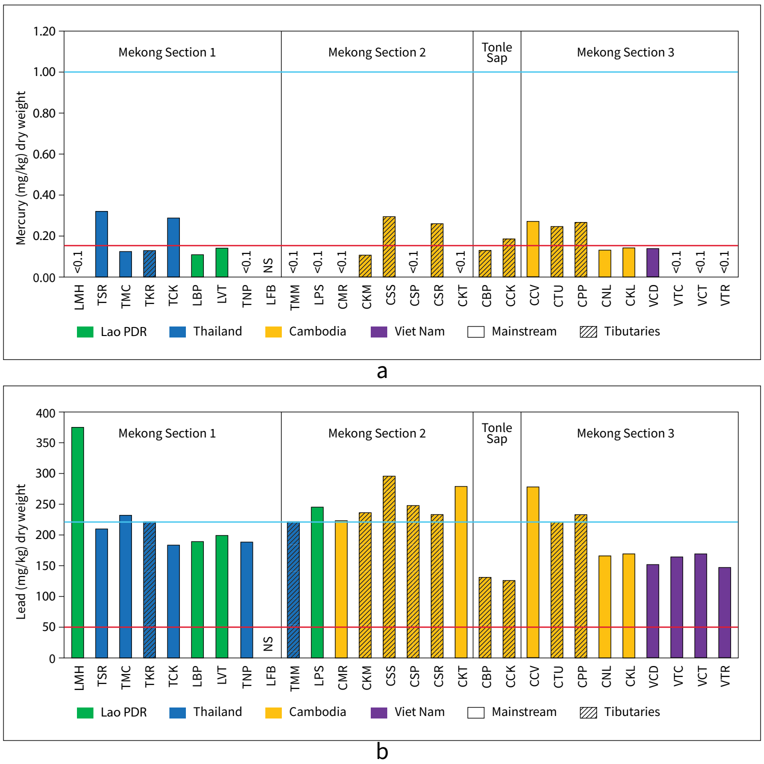
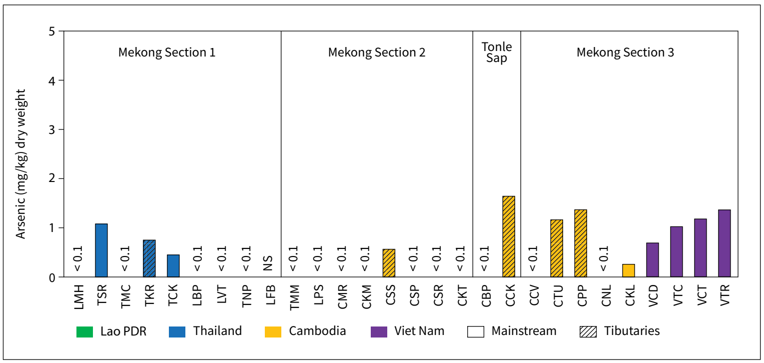
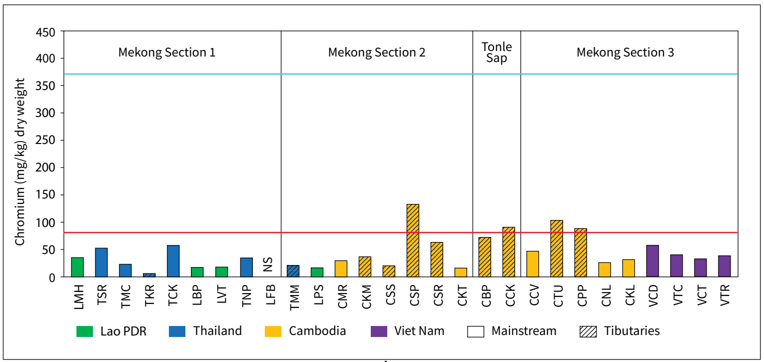


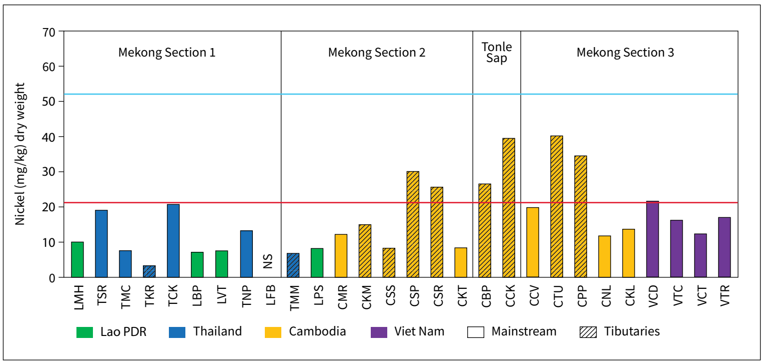
Figure 3-27cont: Comparison of heavy metals in sediment in Mekong River Sections 1, 2, 3 and Tonle Sap region (The horizontal red and blue lines indicate ANZECC upland and lowland river thresholds, respectively).



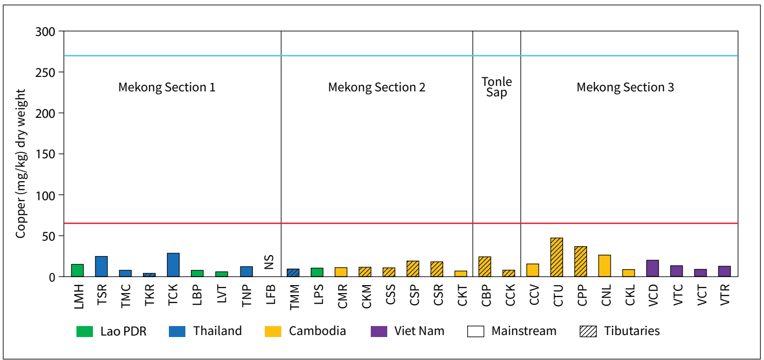
c



d



e



f

the establishment of maximum admissible concentration based on ecotoxicological investigations is difficult. Organisms may become adapted to natural differences. Furthermore, there are challenges in converting the concentrations of the soluble substances used in ecotoxicological studies to appropriate levels in solid phase material, for example soil/sediment, analysed by commonly employed acid digestion procedures. Toxicological thresholds may thus also need to consider a spatial component that is presently neglected.

In the MMMAP, four different methods are demonstrated: namely, a) comparing the total metal concentrations with selected setting threshold; b) normalizing the total metal concentrations with considering co-factors, i.e. percentage of fine particles, percentage of organic matter, and key aluminosilicate compounds (Al and Li); c) using enrichment factor (EF); and d) using geo-accumulation index (I_{geo}).

3.2.2.1 Normalisation of heavy metals in sediment considering co-factors

In order to understand sediment heavy metal distribution – whether they occur naturally due to the baseline concentration in the Mekong Basin or whether they can be partly attributed to the external pollution sources in the basin, the study attempted to analyse sediment heavy metal concentrations using normalisation.

The normalisation procedure is used to consider co-factors – namely percentage of silt and clay (less than 63 µm) and percentage of organic matter or key aluminosilicate compounds (Al or Li) to normalise total concentrations. In other words, the study tests the sediment heavy metal concentrations in sediment with these co-factors by finding out whether there is a linear relationship between total metal concentrations with the co-factor.

The results of normalised heavy metal concentrations in sediment in this study are summarised in Table 3-13. Metals such as Cu, Ni and Cr have a strongly linear relationship with Al indicating that their concentrations in the sediment of the LMB in general come from the baseline (natural rock and soil) concentration rather than from anthropogenic (external pollution) sources. But this is not the case for Pb, Hg and As.

The relationship between organic matter content and heavy metal concentrations in sediment is weak. So, the distribution of heavy metals in sediment of the LMB is less likely to be absorbed with organic matter deposition in sediment.

Cu, Ni and Cr (and probably Pb) are unlikely to be absorbed into finer grain (less than 63 μm) of the sediment. They are likely to be leached from the baseline rock and soil deposits.

The normalised Pb concentrations have no significant positive linear relationship with any co-factors. It is likely that the pollution sources of these heavy metals may come from external anthropogenic sources, not from natural baseline rock and soil of the basin.

Table 3-12: Average metal concentrations in shale and earth's crust.

Metals	Shale*	Crust**
Hg (mg/kg)	0.4	0.08
Cd (mg/kg)	0.3	0.2
Pb (mg/kg)	20	12.5
As (mg/kg)	13	1.8
Cr (mg/kg)	90	100
Ni (mg/kg)	68	76
Cu (mg/kg)	45	55
Al (mg/kg)	80,000	82,300
Li (mg/kg)	66	20

*Turekian and Wedepohl (1961)
**Taylor (1964)

Table 3-13: The summaries of R^2 from normalisation of heavy metal concentration in sediment .

Parameter	log [Al]	log [Li]	log[%<63 um]	log[%OM]
log [Hg]	0.2485	0.0526	0.1366	0.2619
log [Cd]	–	–	–	–
log [Pb]	0.2025	0.3350	0.1403	0.2101
log [As]	0.3082	0.1756	0.1546	0.3532
log [Cr]	0.6441	0.5690	0.3672	0.2517
log [Ni]	0.7408	0.6543	0.3002	0.1952
log [Cu]	0.5722	0.4921	0.3395	0.1833

*All Cd concentrations in the sediment are lower than detection limit

Table 3-14: Enrichment factor classification (Birch and Davies, 2003).

Sediment Enrichment Factor	Contamination Intensity
EF < 1	no enrichment
EF < 3	minor enrichment
EF = 3–5	moderate enrichment
EF = 5–10	moderately severe enrichment
EF = 10–25	severe enrichment
EF = 25–50	very severe enrichment
EF > 50	extremely severe enrichment

The normalised values of heavy metal concentrations in sediment help to identify the source of these heavy metals. Just looking at total concentrations may mistakenly indicate that they come from pollution sources.

Table 3-15: Enrichment factor (EF) of metals for each station studied at the Lower Mekong Basin.

CODE	River Section	Hg	Cd	Pb	As	Cr	Ni	Cu
LMH	S1 – M	–	–	69.6	0.00	0.73	0.29	0.60
TSR	S1 – M	5.64	–	23.7	0.82	0.72	0.35	0.68
TMC	S1 – M	4.49	–	51.6	0.08	0.59	0.26	0.39
TKR	S1 – T	6.73	–	71.1	1.61	0.18	0.15	0.17
TCK	S1 – M	4.76	–	19.7	0.32	0.76	0.36	0.58
LPB	S1 – M	4.05	–	45.1	–	0.46	0.26	0.36
LVT	S1 – M	5.98	–	52.8	–	0.52	0.31	0.33
TNP	S1 – M	2.28	–	30.1	–	0.68	0.34	0.42
LFB	S1 – T	–	–	–	–	–	–	–
TMM	S2 – T	3.36	–	69.9	–	0.76	0.34	0.51
LPS	S2 – M	3.35	–	78.4	–	0.73	0.41	0.66
CMR	S2 – M	3.68	–	59.7	–	1.03	0.53	0.63
CKM	S2 – T	3.19	–	47.9	–	0.94	0.48	0.63
CSS	S2 – T	9.43	–	61.2	0.88	0.50	0.25	0.41
CSP	S2 – T	0.42	–	44.4	–	3.00	0.87	0.77
CSR	S2 – M	4.88	–	28.9	–	1.00	0.51	0.53
CKT	S2 – M	4.76	–	127.0	–	1.03	0.60	0.66
M-CCV	S3 – M	5.93	–	37.8	–	0.80	0.44	0.48
CBP	Tonle Sap	1.41	–	10.0	0.06	0.70	0.33	0.41
CCK	Tonle Sap	2.12	–	9.5	0.86	0.89	0.49	0.15
CTU	S3 –T	2.06	–	12.4	0.46	0.74	0.38	0.59
CPP	S3 – T	2.68	–	15.5	0.64	0.75	0.37	0.56
CNL	S3 – M	3.71	–	29.9	–	0.57	0.34	1.08
CKL	S3 – M	3.15	–	25.3	0.27	0.63	0.31	0.33
VCD	S3 – M	1.78	–	13.2	0.38	0.65	0.31	0.38
VTC	S3 – M	1.90	–	20.0	0.86	0.60	0.33	0.36
VCT	S3 – M	–	–	29.3	1.42	0.67	0.34	0.36
VTR	S3 – M	1.25	–	18.9	1.20	0.61	0.36	0.36
	Average	3.72±1.98	–	40.8±26.6	0.66±0.48	0.79±0.47	0.38±0.13	0.50±0.19
	Range	0.42-9.43	–	9.5-127.0	0.00-1.61	0.18-3.00	0.15-0.87	0.15-1.08

M = Mainstream   T = Tributaries

3.2.2.2 Enrichment factor (EF)

The extent of Mekong River sediment contamination was assessed using the enrichment factor (EF). The EF is reported as an effective tool to differentiate between anthropogenic and naturally occurring sources of heavy metal (Morillo et al., 2004; Selvaraj et al., 2004; Adamo et al., 2005; Vald'es et al., 2005). Using this technique, metal concentrations were normalised to the textural characteristics of sediments. The most widely used element to normalise the metals in sediments is Al since it represents the aluminasilicates, as discussed previously, the predominant contents of coastal sediments. The EF is defined as:

$$EF = \frac{\text{(Metal species concentration in sediment)/(Al concentration in sediment)}}{\text{(Metal species concentration inaverage crust)/(Al concentration in average crust)}}$$

The EF values were interpreted for the metals studied with respect to crust average (Taylor, 1964) as suggested by many authors (for example Birch and Davies, 2003; Chen et al., 2007). Table 3-14 is a classification of the EF values for intensity of contamination (Birch and Davies, 2003). If EF < 1 indicates no enrichment, EF < 3 is minor enrichment, EF = 3–5 is moderate enrichment, EF = 5–10 is moderately severe enrichment, EF = 10–25 is severe enrichment, EF = 25–50 is very severe enrichment, and EF > 50 is extremely severe enrichment.

Table 3-15 and Figure 3-28 present the EF values of the metals studied with respect to crust average (Taylor, 1964). The average EFs are 3.72±1.98 for Hg, 40.8±26.6 for Pb, 0.66±0.48 for As, 0.79±0.47 for Cr, 0.38±0.13 for Ni and 0.50±0.19 for Cu. In general, it indicates that metals such as As, Cr, Ni and Cu show no enrichment, while Hg shows moderate enrichment and Pb has very severe enrichment. Using EF for assessment of metal contamination in the LMB sediment gives that agree with the normalisation results in the previous section.

Figure 3-28: The enrichment factor (EF) and contamination intensity classification of metals in the Lower Mekong Basin's sediments.

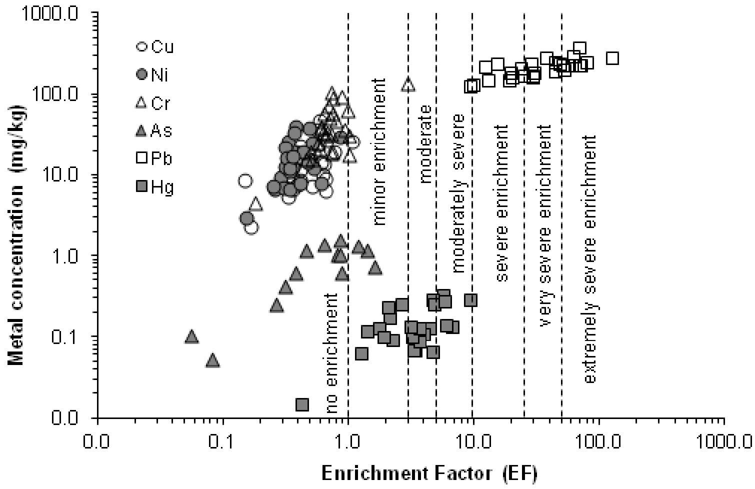


Table 3-16: Enrichment factor classification (Birch and Davies, 2003).

Sediment Geo-accumulation Index (Igeo)	I_{geo} class	Contamination Intensity
< 0	0	practically uncontaminated
> 0 – 1	1	uncontaminated to moderate
> 1 – 2	2	moderately contaminated
> 2 – 3	3	moderately to strongly contaminated
> 3 – 4	4	strongly contaminated
> 4 – 5	5	strongly to very strongly contaminated
> 5	6	very strongly contaminated

3.2.2.3 Index of geo-accumulation (I_{geo})

In this section, the indexing geo-accumulation (I_{geo}), the enrichment on geological

Table 3-17: Geo-accumulation index (I_{geo}) of metals for each station studied in the Lower Mekong Basin.

CODE	River Section	Hg	Cd	Pb	As	Cr	Ni	Cu
LMH	S1 – M	–	–	2.53	–	-1.46	-2.38	-1.55
TSR	S1 – M	-0.63	–	1.95	-2.93	-0.98	-1.70	-0.93
TMC	S1 – M	-1.55	–	2.03	-5.93	-1.87	-2.69	-2.18
TKR	S1 – T	-1.49	–	2.01	-3.29	-3.38	-3.55	-3.38
TCK	S1 – M	-0.74	–	1.81	-3.83	-0.87	-1.62	-1.04
LPB	S1 – M	-1.71	–	1.84	–	-2.16	-2.74	-2.32
LVT	S1 – M	-1.44	–	1.88	–	-2.17	-2.68	-2.51
TNP	S1 – M	-1.90	–	1.82	–	-1.40	-2.09	-1.79
LFB	S1 – T	–	–	–	–	–	–	–
TMM	S2 – T	-2.18	–	2.00	–	-1.95	-2.75	-2.25
LPS	S2 – M	-2.19	–	2.10	–	-2.00	-2.57	-2.00
CMR	S2 – M	-1.92	–	2.01	–	-1.48	-2.14	-1.88
CKM	S2 – T	-1.78	–	2.07	–	-1.29	-1.96	-1.59
CSS	S2 – T	-0.73	–	2.28	-3.47	-1.95	-2.63	-2.05
CSP	S2 – T	-3.69	–	2.10	–	-0.01	-1.25	-1.27
CSR	S2 – M	-0.88	–	2.04	–	-0.75	-1.41	-1.29
CKT	S2 – M	-2.21	–	2.22	–	-2.02	-2.55	-2.37
M-CCV	S3 – M	-0.78	–	2.21	–	-1.06	-1.67	-1.49
CBP	Tonle Sap	-1.64	–	1.45	-5.23	-0.63	-1.37	-1.07
CCK	Tonle Sap	-1.23	–	1.40	-2.50	-0.39	-0.98	-2.06
CTU	S3 –T	-0.95	–	1.98	-2.83	-0.26	-0.93	-0.39
CPP	S3 – T	-0.86	–	2.04	-2.66	-0.42	-1.13	-0.61
CNL	S3 – M	-1.54	–	1.68	–	-1.70	-2.21	-0.97
CKL	S3 – M	-1.51	–	1.72	-4.33	-1.41	-2.09	-1.95
VCD	S3 – M	-1.54	–	1.60	-3.45	-0.84	-1.56	-1.27
VTC	S3 – M	-1.80	–	1.69	-2.96	-1.24	-1.85	-1.66
VCT	S3 – M	–	–	1.72	-2.81	-1.48	-2.16	-1.99
VTR	S3 – M	-2.27	–	1.58	-2.69	-1.27	-1.80	-1.70
	Average	-1.57±0.66	–	1.9±0.3	-3.5±1.0	-1.4±0.7	-2.0±0.6	-1.7±0.6
	Range	-3.69 to -0.63	–	1.4 to 2.5	-5.9 to -2.5	-3.4 to 0.0	-3.5 to -0.9	-3.4 to - 0.4

M = Mainstream   T = Tributaries

substrate approach (Müller, 1979; Forstner et al., 1993) is used to quantify the degree of anthropogenic contamination and compare different metals that appear in different ranges of concentration in the LMB sediments. The I_{geo} values for the metals studied were calculated using Muller's (1979) expression:

$$EF = I_{geo}\left(\frac{\textit{Metal species concentration}}{\textit{1.5 x background content of metal species in average shale}}\right)$$

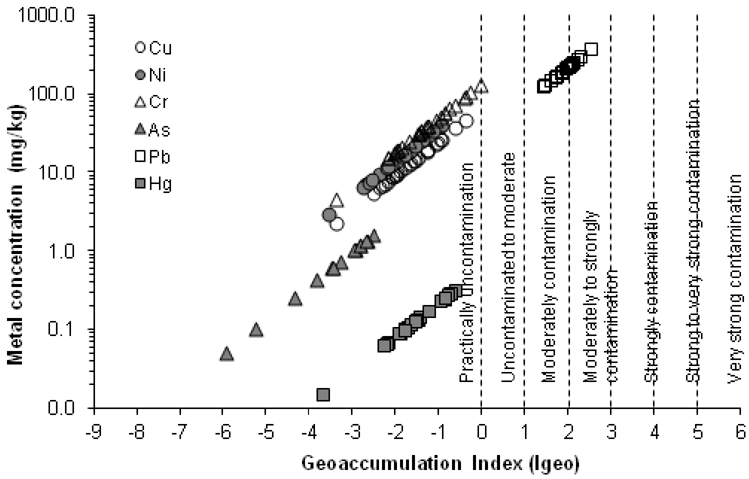
The index of geo-accumulation consists of seven grades, whereby the highest class (class 6) reflects 100-fold enrichment above background values. Förstner et al. (1993) listed geo-accumulation classes and the corresponding contamination intensity for different indices (Table 3-16).

Table 3-17 and Figure 3-29 present the I_{geo} values of the metals studied with respect to shale average (Turekian and Wedepohl, 1961). The average I_{geo} are -1.57±0.66 for Hg, 1.9±0.3 for Pb, -3.5±1.0 for As, -1.4±0.7 for Cr, -2.0±0.6 for Ni and -1.7±0.6 for Cu. In general, these values indicate that metals such as Hg, As, Cr, Ni and Cu are classified as I_{geo} Class 0 which means 'practically uncontaminated', while Pb is classified as I_{geo} Class 2 which means moderate contamination. Using I_{geo} to assess metal contamination in the LMB sediment gives a similar result to other assessment techniques.

3.2.2.4 Summary

In summary, all techniques used to assess metal contamination in the LMB sediment agree that Pb in the sediment shows

Figure 3-29: Geo-accumulation index (I_{geo}) and contamination intensity classification of metals in the Lower Mekong Basin's sediments.



somewhat contamination above selected background, while Hg shows that the level is slightly affected from anthropogenic sources. Therefore, reassessment for Pb is strongly recommended in the next monitoring program.

However, as mentioned earlier, sediment data can be misinterpreted due to the natural high variations of element background concentrations in the sediment. Although global background averages are commonly used, particularly for EF and I_{geo} techniques, it has to be kept in mind that the background may change from area to area within a region and between regions. Using deeper sediment levels to judge element concentrations in upper sediment horizons (TOP/BOT-ratio) is also problematic because naturally occurring biogeochemical soil formation processes may change with time.

Table 3-18: Range (minimum – maximum) and average (± s.d) of organic micro-pollutants in sediment in the Mekong River mainstream, tributaries and other studies.

Parameter	Total PCB (mg/kg dry weight)	Hexachloro benzene (HCB) (mg/kg dry weight)	Total Organochlorine Pesticide									
			p p' -DDT (mg/kg dry weight)	p p' -DDE (mg/kg dry weight)	p p' -DDD (mg/kg dry weight)	Endrin Aldehyde (mg/kg dry weight)	Endosulfan Sulfate (mg/kg dry weight)	Heptachlor (mg/kg dry weight)	Heptachlor Epoxide (mg/kg dry weight)	α-Hexachloro Cyclohaxane (mg/kg dry weight)	γ-Hexachloro Cyclohaxane (mg/kg dry weight)	Chlordane (CHL) (mg/kg dry weight)
THIS STUDY												
Mekong River Mainstream												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Tributaries of Mekong												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
OTHER STUDY												
Mekong River mainstream												
(Nguyen H. M., 2007) Mekong River in South Viet Nam Section (ng/g)	0.89	0.016	2.5	1.3	2.5							0.93
SEDIMENT STANDARD												
ANZECC Upland River			0.0016	0.0022	0.002							0.0005
ANZECC Lowland River			0.046	0.027	0.020							0.0006

To date, there is no single approach to quantify sediment quality. The easiest and most reliable technique is normalisation of the total metal concentration by the co-factors, namely a percentage of fine grain sediment, percentage of organic matter or key aluminosilicate compounds (Al or Li). In other words, the study tests the sediment heavy metal concentrations in sediment with these co-factors by finding out whether there is a linear relationship between total metal concentrations with the co-factor.

3.2.3 ORGANIC MICRO-POLLUTANTS

Concentration of organic micro-pollutants in bottom sediment along the Mekong River is shown in Tables 3-18 and 3-19. Organic micro-pollutants data from other studies are provided as a comparison.

The 12 compounds of organic micro-pollutants and groups accumulated in Mekong sediment are well below detection limits (Tables 3-18 and 3-19). In comparison with other studies of the Mekong River in south Viet Nam, where the magnitude of organic micro-pollutants was significant, the level found in this study was very low. This indicates that the sediment is unpolluted in terms of organic micro-pollutants.

3.2.4 MULTIVARIABLE ANALYSIS OF BOTTOM SEDIMENT QUALITY

Multivariable analysis of sediment quality data was treated by Hierarchical Cluster Analysis (HCA) and Principle Component Analysis (PCA) and was based on heavy metal results. Therefore, only stations that

Figure 3-30: Multivariate analysis of all sediment quality in term of heavy metal contamination for the MMMAP, (a) Hierarchical Cluster Analysis (HCA) dendrogram and (b) Principle Component Analysis (PCA) loading score plot

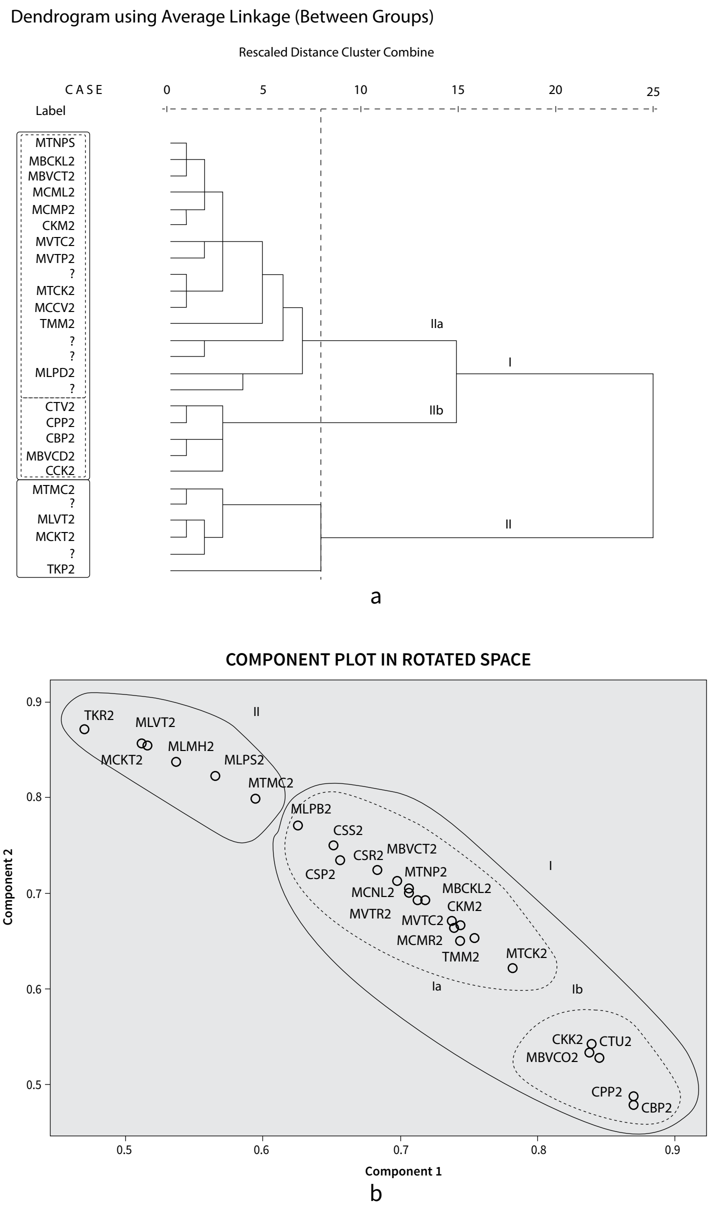


Table 3-19: Range (minimum – maximum) and average (± s.d) of organic micro-pollutants in sediment in the Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Total PCB (mg/kg dry weight)	Hexachloro benzene (HCB) (mg/kg dry weight)	Total Organochlorine Pesticide									
			p p' -DDT (mg/kg dry weight)	p p' -DDE (mg/kg dry weight)	p p' -DDD (mg/kg dry weight)	Endrin Aldehyde (mg/kg dry weight)	Endosulfan Sulfate (mg/kg dry weight)	Heptachlor (mg/kg dry weight)	Heptachlor Epoxide (mg/kg dry weight)	α-Hexachloro Cyclohaxane (mg/kg dry weight)	γ-Hexachloro Cyclohaxane (mg/kg dry weight)	Chlordane (CHL) (mg/kg dry weight)
THIS STUDY												
Mekong Section 1												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Mekong Section 2												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Mekong Section 3												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Tonle Sap												
Min – Max	-	-	-	-	-	-	-	-	-	-	-	-
Avg ± SD	-	-	-	-	-	-	-	-	-	-	-	-
SEDIMENT STANDARD												
ANZECC Upland River			0.0016	0.0022	0.002							0.0005
ANZECC Lowland River			0.046	0.027	0.020							0.0006

Remarks
Section 1 = Stations 1 to 9 (9 Stations)
Section 2 = Stations 10 to 17 (8 Stations)
Section 3 = Stations 18, 21 to 28 (9 Stations)
Tonle Sap = Stations19 and 20 (2 Stations)

analysed for heavy metals were included (27 out of 28 stations), i.e. all stations except Xe Bang Fai (LFB), which is a tributary station.

It should be noted that in this analysis if the value is less than detection limit, the average value is used. If one station is missing, that variable will automatically be excluded. Station names are indicated and categorised into 4 different sections of the LMB (upper, central, lower and Tonle Sap) with the following codes:

- B1 – Station on Mekong River Section 1 – upper part of the LMB (Stations 1–9)
- B2 – Station on Mekong River Section 2 – central part of the LMB (Stations 10–17)
- B3 – Station on Mekong River Section 3 – lower part of the LMB (Stations 18, 21–28)
- B4 – Station on Tonle Sap Sub-section (Stations 19–20).

The HCA dendrogram and PCA loading score plot of the MMMAP sediment quality stations, analysis using all geological and geochemical parameters, are shown in Figure 3-30. The results can be categorised by sampling stations into 2 main groups.

- The first group (group I) can be divided into 2 sub-groups:
  – Subgroup Ia consists of Nakhon Phanom (TNP), Koh Khel (CKL), Can Tho (VCT), Neak Loung (CNL), Stung Treng (CMR), Siem Pang (CKM), Tan Chau (VTC), My Thuan (VTR), Sob Roak (TSR), Chiang Khong (TCK), Chroy Changvar (CCV), Kong Chiam (TMM), Lumphat (CSP), Sekong River Mouth (CSR), Luang Prabang (LPB) and Andoung Meas (CSS)
  – Subgroup Ib consists of Prek Kdam (CTU), Phnom Penh Port (CPP), Back Prea (CBP), Chau Doc (VCD) and Phnom Krom (CCK). Most stations are located in the Great Lake and Tonle Sap.
- The second group (group II) consists of Chiang Sean Pier (TMC), Pakse (LPS), Vientiane (LVT), Kratie (CKT), Houa Khong (LMH) and Kok River mouth (TKR).

Figure 3-31: PCA loading score plot of sediment sampling at all stations by region for heavy metal parameters.

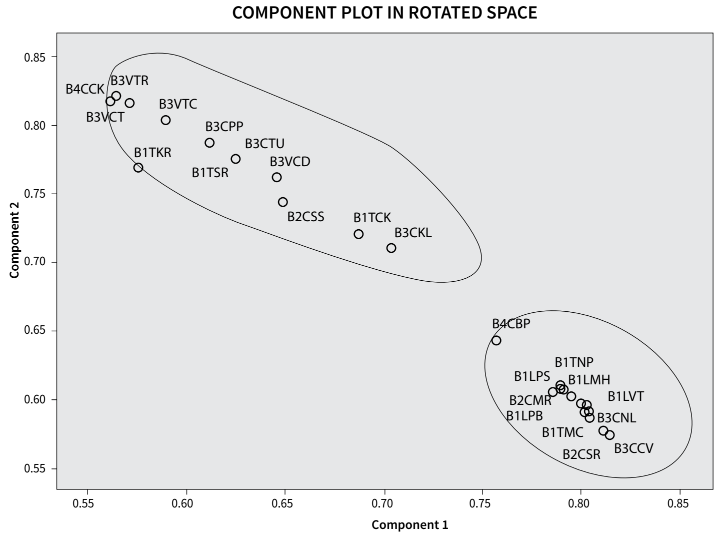
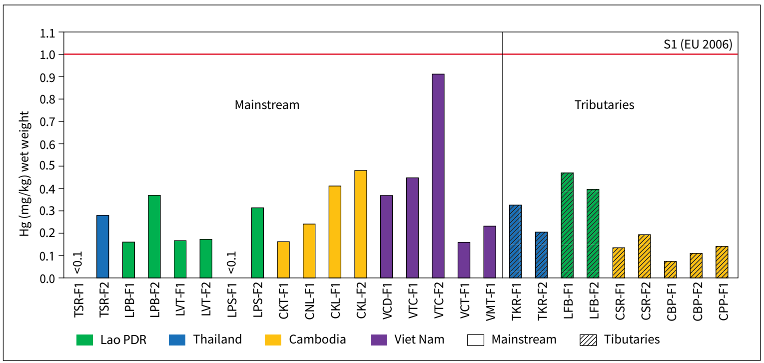


Table 3-20: Rotated component matrix of heavy metal parameters in sediment samples.

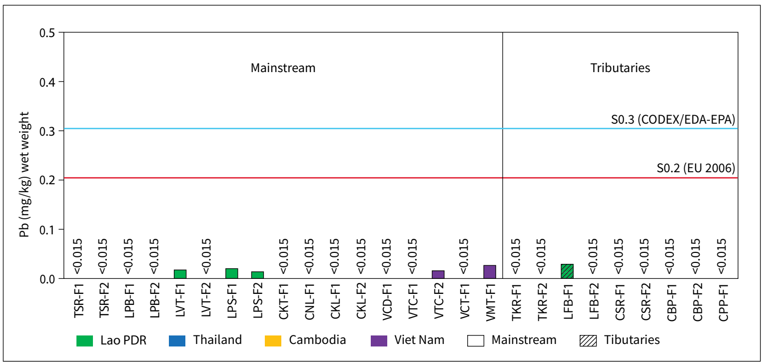
Variables	Component	
	1	2
Hg	0.36	0.06
Pb	-0.09	-0.69
As	0.15	0.83
Cr	0.94	0.27
Ni	0.91	0.38
Cu	0.94	-0.07
% Cumulative	80.5	9.6

*All Cd concentrations in the sediment are lower than detection limit

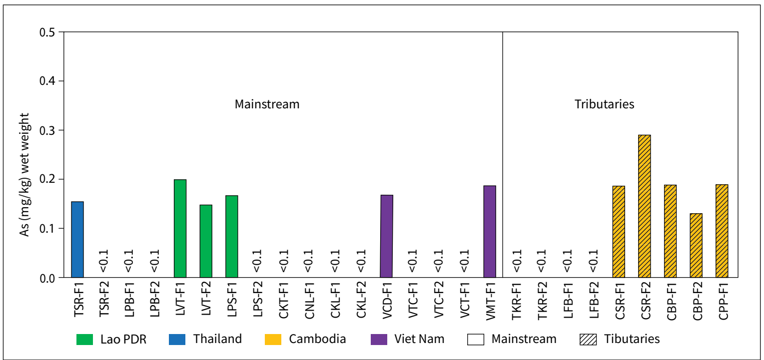
Figure 3-32: Comparison of heavy metals in carnivorous fish tissue in the Mekong River mainstream and tributaries (The horizontal red and blue lines indicate EU2006, CODEX and FDA/EPA , respectively. F1 and F2 mean different species found in each station.



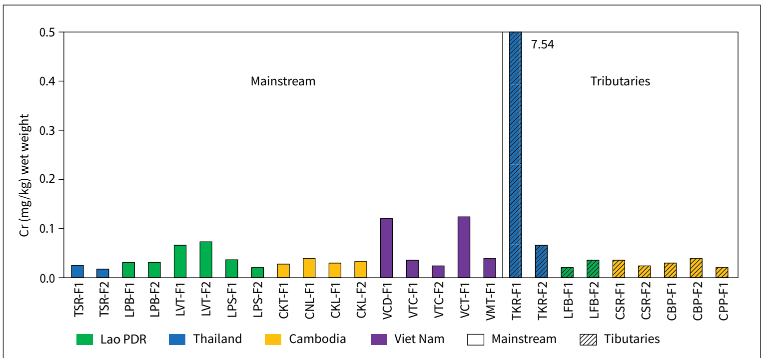
a



b



c



d

Each group is obviously located in a different segment of the LMB. From left to right (Figure 3-30b), all sampling stations in group II are located in the upper part of the Mekong River. Group I represents the sampling stations in the middle and lower parts of the LMB; group Ib are stations containing a high level of fine grain particles and high in organic content.

3.2.4.1 Component matrix of MRC sediment samples

With regard to metal contamination, most of the variance in heavy metals was explained by 2 components (Table 3-20 and Figure 3-31). Component 1 (PC1), which represented the variation of Cr, Ni and Cu, accounted for 80.5% of the total variance. Component 2 (PC2), which represented only the variation of As, accounted for 9.6% of total variance. The results show that the upper part of the LMB (Mekong River Section 1) is different from Section 3 of the river near the delta. It indicates that heavy metals accumulated in the upper and the lower parts of the LMB are controlled by different geological and geochemical factors. The percentage of fine grain particles in sediment of the lower part of the LMB is higher than in sediment of the upper part (see Section 3.2.1).

3.3 BIOTA

Details of individual samples of fish from 17 stations and molluscs from 12 stations are shown in Table 2-3. Comparison of metals and organomicro-pollutants accumulated in edible tissue of fish and molluscs are discussed below.

3.3.1 FISH

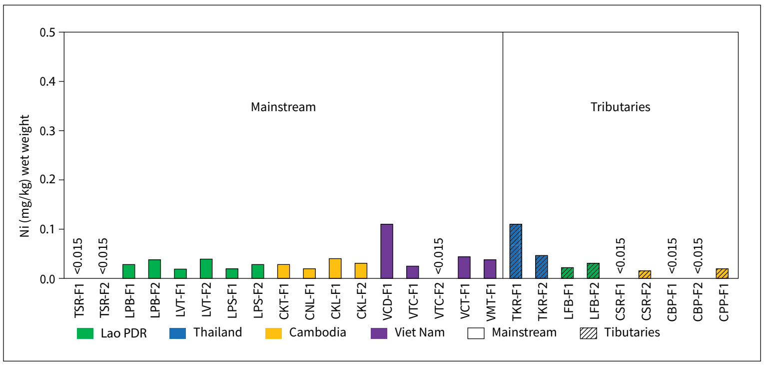
All fish collected in this study are benthopelagic fish and can be divided into 3 groups depending on their feeding behaviour – carnivorous, omnivorous and herbivorous fish. Based on actual sampling, carnivorous fish were found at most stations (16 stations), while omnivorous and herbivorous fish were found at only 5 and 3 stations, respectively. Consequently, this study focused on benthopelagic carnivorous fish, as data representatives.

3.3.1.1 Benthopelagic fish

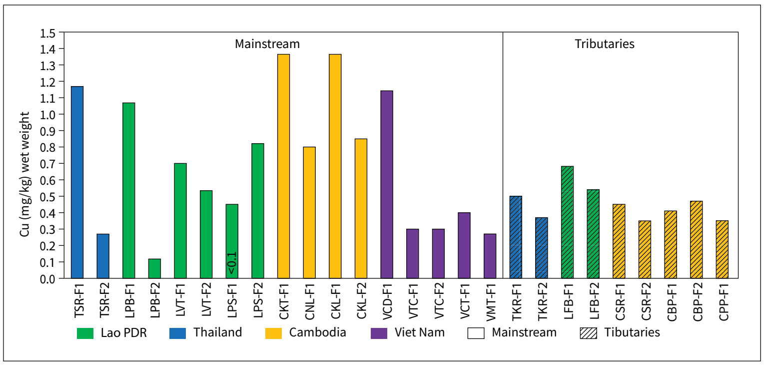
3.3.1.1.1 Heavy Metals

The heavy metals accumulated in fish tissue are presented in Tables 3-21 and 3-24 for carnivorous fish, Tables 3-22 and 3-25 for herbivorous fish and Tables 3-23 and 3-26 for omnivorous fish. The heavy metal data from other studies are provided for comparison.

Figure 3-32 cont.: Comparison of heavy metals in carnivorous fish tissue in the Mekong River mainstream and tributaries (The horizontal red and blue lines indicate EU2006, CODEX and FDA/EPA , respectively. F1 and F2 mean different species found in each station.



e



f

Refer to guidelines for heavy metal in fish tissue. Guidelines are available for three high toxicity metals, namely mercury (Hg), cadmium (Cd) and lead (Pb). All guidelines aim to protect human health on fish consumption. The data in this study indicated that Hg, Cd and Pb accumulated in the edible fish tissue at all stations do not exceed any of the following standard thresholds:

- Hg: EU 2006 – 0.5 mg/kg for most fish and 1 mg/kg for predatory fish
- Cd: EU 2006 – 0.05 mg/kg
  CODEX – 1 mg/kg
- Pb: EU 2006 – 0.2 mg/kg
  CODEX and FDA/EPA – 0.3 mg/kg

Metals accumulated in edible tissues of carnivorous fish collected from mainstream and tributaries were found in the same range (Tables 3-21 and 3-24). Only two samples from Tan Chao (VTC) (0.9 mg/kg) and Phnom Penh Port (CPP) (0.6 mg/kg) contained Hg higher than 0.5 mg/kg but lower than the EU (2006) guideline of 1 mg/kg (Figures 3-32a and 3-33a).

In comparison with other studies (Table

Table 3-21: Range (minimum – maximum) and average (± s.d.) of heavy metals in carnivorous fish tissue in the Mekong River mainstream tributaries and other studies.

Parameter	Hg (mg/kg) wet weight	Cd (mg/kg) wet weight	Pb (mg/kg) wet weight	As (mg/kg) wet weight	Cr (mg/kg) wet weight	Ni (mg/kg) wet weight	Cu (mg/kg) wet weight
THIS STUDY							
Mekong River Mainstream							
Min – Max	<0.1-0.90*	<0.005-0.007	<0.015-0.035	<0.100-0.22	<0.015-0.121	<0.015-0.112	0.118-1.35
Avg ± SD	0.29±0.204	0.003±0.001	0.012±0.008	0.095±0.064	0.04±0.032	0.03±0.02	0.69±0.41
Tributaries							
Min – Max	0.125-0.571	<0.005	<0.015-0.03	<0.100-0.28	0.017-7.540	<0.015-0.107	0.33-0.67
Avg ± SD	0.32±0.15	-	0.01±0-009	0.13±0-08	0.87±1.87	0.028±0.03	0.45±0.28
OTHER STUDY							
Nguyen Ngoc Trang, 2006							
Duy Minh River			0.04-0.44		0.02-0.38		16.-64
Saigon River	0.07		0.02		0.17		1.5
BIOTA QUALITY STANDARD							
EU 2006	1	0.05	0.2	-	-	-	-
CODEX	-	1	0.3	-	-	-	-
EDA/EPA	-	-	0.3	-	-	-	-

Table 3-22: Range (minimum – maximum) and average (± s.d.) of heavy metals in herbivorous fish tissue in the Mekong River mainstream and tributaries.

Parameter	Hg (mg/kg) wet weight	Cd (mg/kg) wet weight	Pb (mg/kg) wet weight	As (mg/kg) wet weight	Cr (mg/kg) wet weight	Ni (mg/kg) wet weight	Cu (mg/kg) wet weight
THIS STUDY							
Mekong River Mainstream							
Min – Max	0.147	0.007	<0.015	<0.100	0.04	0.032	0.518
Avg ± SD							
Tributaries							
Min – Max	0.147-0.225	<0.005	<0.015	<0.100	0.04-0.177	0.032-0.037	0.518-1.00
Avg ± SD	0.19±0.06	<0.005	<0.015	<0.100	0.11±0.097	0.035±0.004	0.759±0.341
BIOTA QUALITY STANDARD							
EU 2006	1	0.05	0.2	-	-	-	-
CODEX	-	1	0.3	-	-	-	-
EDA/EPA	-	-	0.3	-	-	-	-

Table 3-23: Range (minimum – maximum) and average (± s.d) of heavy metals in omnivorous fish tissue in the Mekong River mainstream and tributaries.

Parameter	Hg (mg/kg) wet weight	Cd (mg/kg) wet weight	Pb (mg/kg) wet weight	As (mg/kg) wet weight	Cr (mg/kg) wet weight	Ni (mg/kg) wet weight	Cu (mg/kg) wet weight
THIS STUDY							
Mekong River Mainstream							
Min – Max	0.16-0.49	<0.005	<0.015-0.156	<0.100-0.333	<0.015-0.077	0.04-0.09	0.34-0.59
Avg ± SD	0.33±0.16	<0.005	0.057±0.086	0.186±0.142	0.042±0.03	0.06±0.033	0.42±0.15
Tributaries							
Min – Max	0.13-0.27	<0.005	<0.015	<0.100	0.025-0.10	0.025-0.062	0.48-1.250
Avg ± SD	0.21±0.07				0.065±0.04	0.041±0.02	0.877±0.38
BIOTA QUALITY STANDARD							
EU 2006	1	0.05	0.2	-	-	-	-
CODEX	-	1	0.3	-	-	-	-
EDA/EPA	-	-	0.3	-	-	-	-

Table 3-24: Range (minimum – maximum) and average (± s.d) of heavy metals in carnivorous fish tissue in the Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Hg (mg/kg) wet weight	Cd (mg/kg) wet weight	Pb (mg/kg) wet weight	As (mg/kg) wet weight	Cr (mg/kg) wet weight	Ni (mg/kg) wet weight	Cu (mg/kg) wet weight
THIS STUDY							
Mekong River Section 1							
Min – Max	<0.100-0.463	<0.005-0.007	<0.015-0.035	<0.100-0.197	<0.015-7.540	<0.015-0.107	0.118-1.15
Avg ± SD	0.26±0.131	0.003±0.001	0.012±0.01	0.085±0.057	0.79±2.37	0.032±0.029	0.591±0.324
Mekong River Section 2							
Min – Max	<0.100-0.361	<0.005	<0.015-0.017	<0.100-0.284	0.020-0.035	<0.015-0.025	0.348-1.350
Avg ± SD	0.268-0.087		0.011±0.005	0.170±0.096	0.026±0.007	0.018±0.007	0.681±0.42
Mekong River Section 3							
Min – Max	0.153-0.900*	<0.005-0.007	<0.015-0.025	<0.100-0.220	0.02-0.121	<0.015-0.112	0.277-1.360
Avg ± SD	0.42±0.22	0.003±0.002	0.001±0.006	0.099±0.074	0.049±0.04	0.036±0.031	0.64±0.413
Tonle Sap							
Min – Max	0.125-0.155	<0.005	<0.015	0.126-0.185	0.025-0.035	<0.015	0.399-0.469
Avg ± SD	0.140±0.021			0.156±0.042	0.030±0.007		0.434±0.049
BIOTA QUALITY STANDARD							
EU 2006	1	0.05	0.2	-	-	-	-
CODEX	-	1	0.3	-	-	-	-
EDA/EPA	-	-	0.3	-	-	-	-

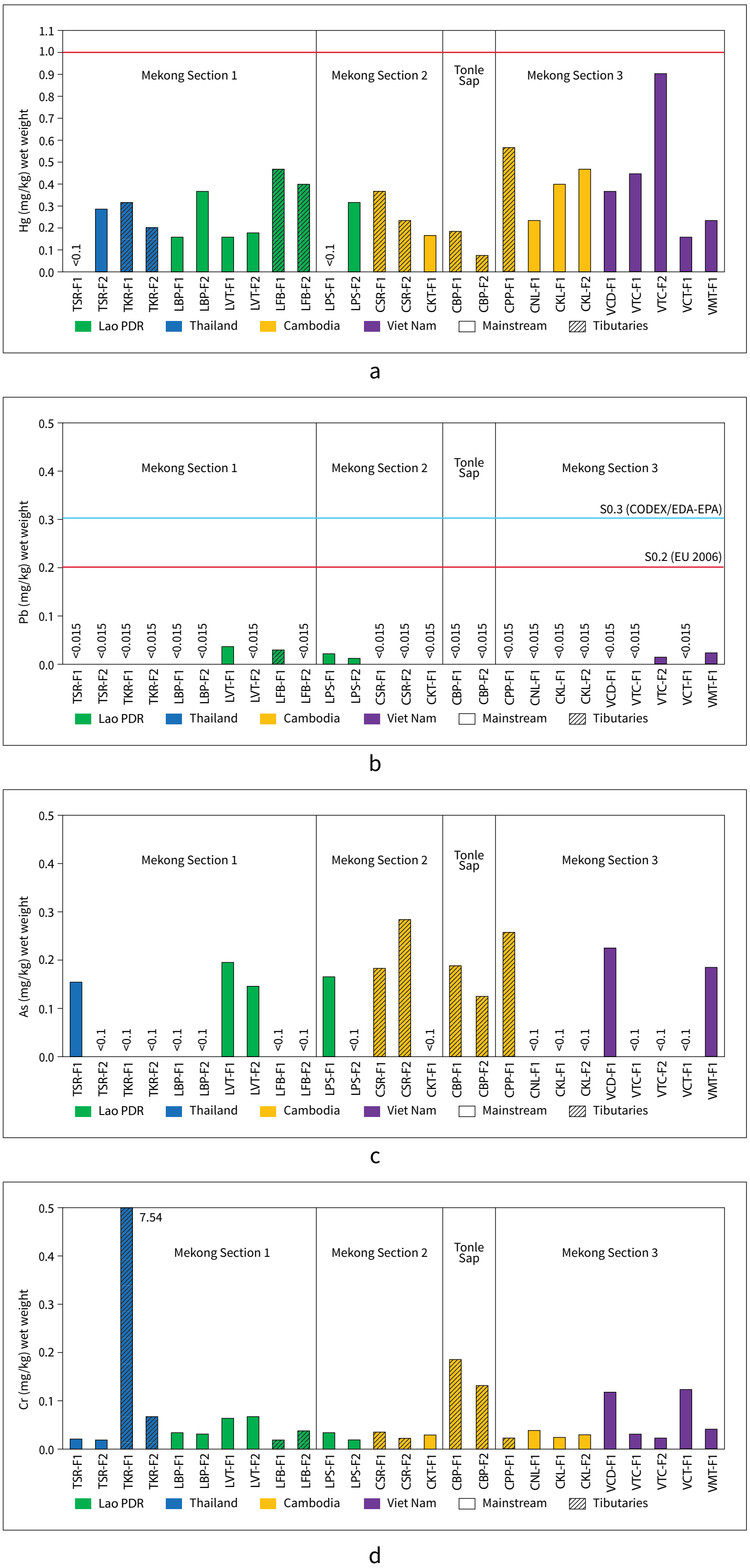
Table 3-25: Range (minimum – maximum) and average (± s.d.) of heavy metals in herbivorous fish tissue in the Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Hg (mg/kg) wet weight	Cd (mg/kg) wet weight	Pb (mg/kg) wet weight	As (mg/kg) wet weight	Cr (mg/kg) wet weight	Ni (mg/kg) wet weight	Cu (mg/kg) wet weight
THIS STUDY							
Mekong River Section 1							
Min – Max	0.225-0.349	<0.005-0.007	<0.015	<0.1	0.032-0.177	0.012-0.032	0.518-1.31
Avg ± SD	0.28±0.088	0.007			0.105±0.103	0.022±0.014	0.914±0.56
Mekong River Section 2							
Min – Max	-	-	-	-	-	-	-
Avg ± SD	-	-	-	-	-	-	-
Mekong River Section 3							
Min – Max	0.147	<0.005	<0.015	<0.100	0.04	0.037	1.00
Avg ± SD	-	-	-	-	-	-	-
Tonle Sap							
Min – Max	-	-	-	-	-	-	-
Avg ± SD	-	-	-	-	-	-	-
BIOTA QUALITY STANDARD							
EU 2006	1	0.05	0.2	-	-	-	-
CODEX	-	1	0.3	-	-	-	-
EDA/EPA	-	-	0.3	-	-	-	-

Table 3-26: Range (minimum – maximum) and average (± s.d.) of heavy metals in omnivorous fish tissue in the Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Hg (mg/kg) wet weight	Cd (mg/kg) wet weight	Pb (mg/kg) wet weight	As (mg/kg) wet weight	Cr (mg/kg) wet weight	Ni (mg/kg) wet weight	Cu (mg/kg) wet weight
THIS STUDY							
Mekong River Section 1							
Min – Max	0.35	<0.005	<0.015	0.333	0.077	0.04	0.59
Avg ± SD	-	-	-	-	-	-	-
Mekong River Section 2							
Min – Max	0.129-0.274	<0.005	<0.015	<0.100	0.025-0.1	0.025-0.062	0.482-1.25
Avg ± SD	0.210-0.074				0.065±0.038	0.041±0.019	0.877±0.38
Mekong River Section 3							
Min – Max	0.162-0.489	<0.005	<0.015-0.156	<0.100-0.175	<0.015-0.037	<0.015-0.087	0.336-0.337
Avg ± SD	0.33±0.23		0.156	0.175	0.026±0.016	0.047±0.056	0.337±0.001
Tonle Sap							
Min – Max	-	-	-	-	-	-	-
Avg ± SD	-	-	-	-	-	-	-
BIOTA QUALITY STANDARD							
EU 2006	1	0.05	0.2	-	-	-	-
CODEX	-	1	0.3	-	-	-	-
EDA/EPA	-	-	0.3	-	-	-	-

Figure 3-33: Comparison of heavy metals in carnivorous fish tissue in the Mekong River Sections 1, 2, 3 and Tonle Sap (The horizontal red and blue lines indicate EU2006, CODEX and FDA/EPA, respectively. F1 and F2 mean different species found at each station.



3-21), the level of heavy metals accumulated in edible tissue of fish in the Mekong River are in the same magnitude as those found in fish living in Duy Minh and Saigon Rivers except for Hg (Nguyen Ngoc Trang, 2006) Contamination of metals in fish collected from the Duy Minh River was found to be 16–64 mg Cu/kg, 0.02–0.38 mg Cr/kg, 0.37–1.09 mg Pb/kg and 0.04–0.44 mg Cd/kg (on wet weight basis). Snakehead fish in the Saigon River contained 1.5 mg Cu/kg, 0.8 mg Cr/kg, 0.17 mg Pb/kg, 0.02 mg Cd/kg and 0.07 mg Hg/kg (on wet weight basis).

Although Hg content in the Saigon River seems to be very low when compared with this study, the Hg level in edible tissue of fishes in the LMB in this study is still in the range of those found in Songkhla Lake where the average (min–max) Hg concentration in carnivorous, omnivorous and herbivorous fish was 0.095 ± 0.108 (0.011–0.625), 0.036 ± 0.022 (0.012–0.033) and 0.033 ± 0.032 (0.012–0.070) mg/kg wet weight as shown in Figure 3-34 (Sukapan et al., 2006).

Comparison of results between Mekong River sections is shown in Table 3-24. The concentrations for all heavy metals are in a similar magnitude and there is not much difference between the 4 sections except for Hg which seems to be higher in the downstream section. Similarly, comparison of surface water results showed an increasing trend of dissolved and particulate Hg from upstream to down stream (Figures 3-12a and 3-12b).

3.3.1.1.1.1 Comparison of Heavy Metal Contamination in same fish species.

To investigate spatial distribution of heavy metals in edible fish tissue of selected species along the Mekong, yellow catfish (*Hemibargus nemurus*) and long bartel fish (*Pangasius macronema*) were caught at several stations and compared (Table 3-27).

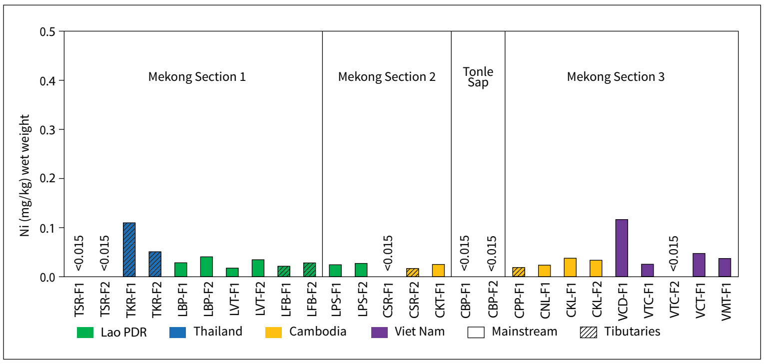
1. Yellow catfish (*Hemibargus nemurus*) at 8 sampling stations, located and distributed along the Mekong River, namely Sob Rouak (TSR) and Kok River mouth (TKR), Luang Prabang (LPB), Xe Bang Fai (LFB), Sekong River mouth (CSR), Koh Khel (CKL), Chau Doc (VCD) and Tan Chao (VTC).

2. Long bartel fish (*Pangasius macronema*) at 5 sampling stations, namely Sob Rouak (TSR), Sekong River mouth (CSR), Kratie (CKT), Tan Chao (VTC) and Can Tho (VCT).

Comparing the same fish species, for both yellow catfish and long bartel fish, the results were of a similar magnitude (Table 3-27). The concentration of Cd and Pb accumulated in the fish tissues was lower than the detection limit of 0.005 and 0.015 mg/kg wet weight, respectively. This indicates that the Cd and Pb content are well below the EU 2006 and EDA/EPA thresholds. As, Cr, Ni, and Cu concentrations in fish tissue were very low to low, close to the detection limits of 0.1, 0.015, 0.015 and 0.005 mg/kg wet weight, respectively.

Only Hg in one composite sample of yellow catfish collected at Tan Chao (VTC) was elevated and close to the threshold of 1

Figure 3-33 cont.: Comparison of heavy metals in carnivorous fish tissue in the Mekong River Sections 1, 2, 3 and Tonle Sap (The horizontal red and blue lines indicate EU2006, CODEX and FDA/EPA, respectively. F1 and F2 mean different species found at each station).



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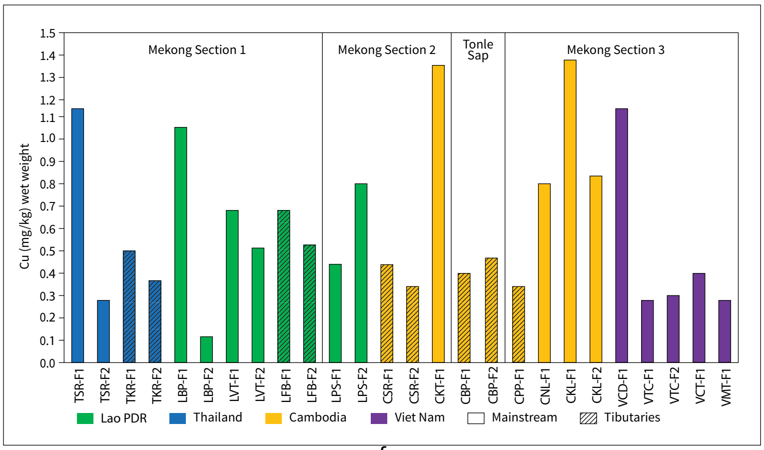

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Figure 3-34: Mercury content in edible tissue of fishes collected in Songkhla Lake, Thailand showing a box-plot comparison of median and range among carnivorous, omnivorous, herbivorous fishes and shrimp (N means number of samples, the thick line in the box means median, the upper and lower lines outside the box mean 75 and 25 percentiles, open circle and star mean outlier data) (Sukapan et al., 2006)).

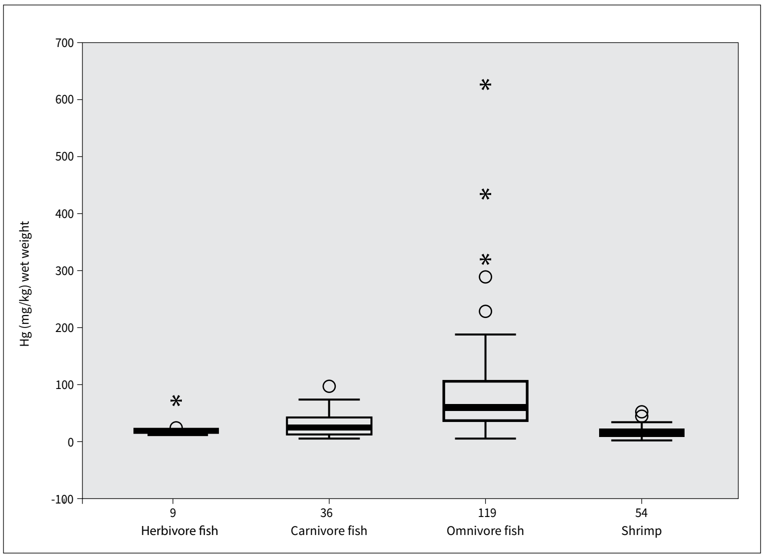


Table 3-27: Range (minimum – maximum) and average (± s.d.) of heavy metals in 2 Mekong River fish species.

Parameter	Hg (mg/kg) wet weight	Cd (mg/kg) wet weight	Pb (mg/kg) wet weight	As (mg/kg) wet weight	Cr (mg/kg) wet weight	Ni (mg/kg) wet weight	Cu (mg/kg) wet weight
Yellow catfish (*Hemibargus nemurus*)							
Min – Max	0.204-0.9*	<0.005	<0.015	<0.1-0.28	0.015-0.117	<0.015-0.112	0.118-1.14
Avg ± SD	0.404±0.22	-	-	0.101±0.095	0.042±0.03-	0.035±0.034	0.491±0.34
Long bartel fish *Pangasius macronema*							
Min – Max	<0.1-0.448	<0.005	<0.015	<0.1-0.183	0.02-0.121	<0.015-0.044	0.29-1.35
Avg ± SD	0.235±0.164			0.097±0.065	0.047±0.042	0.021±0.015	0.725±0.49
BIOTA QUALITY STANDARD							
EU 2006	1	0.05	0.2	-	-	-	-
CODEX	-	1	0.3	-	-	-	-
EDA/EPA	-	-	0.3	-	-	-	-

Table 3-28: Range (minimum – maximum) and average (± s.d.) of organic micro-pollutants in fish tissue in the Mekong River mainstream, tributaries and other studies.

Parameter	Total PCB (mg/kg wet weight)	Hexachloro benzene (HCB) (mg/kg wet weight)	Total Organochlorine Pesticide									
			p̧ p' -DDT (mg/kg wet weight)	p̧ p' -DDE (mg/kg wet weight)	p̧ p' -DDD (mg/kg wet weight)	Endrin Aldehyde (mg/kg wet weight)	Endosulfan Sulfate (mg/kg wet weight)	Heptachlor (mg/kg wet weight)	Heptachlor Epoxide (mg/kg wet weight)	α-Hexachloro Cyclohaxane (mg/kg wet weight)	γ-Hexachloro Cyclohaxane (mg/kg wet weight)	Chlordane (CHL) (mg/kg wet weight)
THIS STUDY												
Mekong River Mainstream												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Tributaries of Mekong River												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1

mg/kg. Compared with the average Hg concentration, this is elevated to a level of significance, but it is still less than half the threshold tissue concentration (EU, 2006 at 1.0 mg/kg).

It should be noted that all results were conducted only once and using a composite sample. It is difficult to specify the source of pollution. Further detailed study of Hg accumulation in fish tissue is needed and close monitoring by analysis of individual fish rather than composite samples.

3.3.1.1.2 Organic Micro-Pollutants

The results for organic micro-pollutants accumulated in fish tissue are presented in Table 3-28. All organic micro-pollutants accumulated in all fish groups (carnivorous, omnivorous and herbivorous) in this study were below the detection limit. Organic micro-pollutant data from other studies are provided as a comparison.

The 12 compounds of organic micro-pollutants and groups accumulated in fish tissue living in the Mekong River are well below the detection limits (Tables 3-28 and 3-29). In comparison with the FDA/EPA guideline for PCBs and organochlorine pesticides, such as DDT, heptachlor, chlordane etc., the detection limits used in this study were lower than the guidelines. This indicates that the health risk to fish consumers is low and at a safe level.

Figure 3-35: PCA loading score plot of 26 carnivorous fish sampled at 15 stations by region for heavy metal parameters.

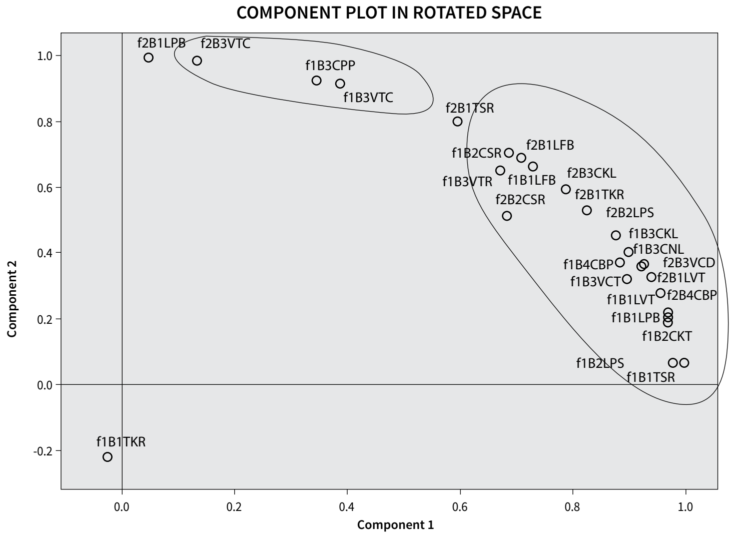


Table 3-30: Rotated component matrix of heavy metal parameters in 26 carnivorous samples.

Variables	Component	
	1	2
Hg	-0.03	-0.32
Pb	-0.11	-0.03
As	-0.17	-0.06
Cr	0.98	-0.19
Ni	0.67	0.08
Cu	0.14	0.98
% Cumulative	72.6	18.6

Table 3-29: Range (minimum – maximum) and average (± s.d.) of organic micro-pollutants in fish tissue in the Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Total PCB (mg/kg wet weight)	Hexachloro benzene (HCB) (mg/kg wet weight)	Total Organochlorine Pesticide									
			p,p'-DDT (mg/kg wet weight)	p,p'-DDE (mg/kg wet weight)	p,p'-DDD (mg/kg wet weight)	Endrin Aldehyde (mg/kg wet weight)	Endosulfan Sulfate (mg/kg wet weight)	Heptachlor (mg/kg wet weight)	Heptachlor Epoxide (mg/kg wet weight)	α-Hexachloro Cyclohaxane (mg/kg wet weight)	γ-Hexachloro Cyclohaxane (mg/kg wet weight)	Chlordane (CHL) (mg/kg wet weight)
THIS STUDY												
Mekong River Section 1												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Mekong River Section 2												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Mekong River Section 3												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Tonle Sap												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1

Remarks
Section 1 = Stations 1 to 9 (9 Stations)
Section 2 = Stations 10 to 17 (8 Stations)
Section 3 = Stations 18, 21 to 28 (9 Stations)
Tonle Sap = Stations19 and 20 (2 Stations)

3.3.1.2 Multivariable analysis of carnivorous fish samples (heavy metal contamination)

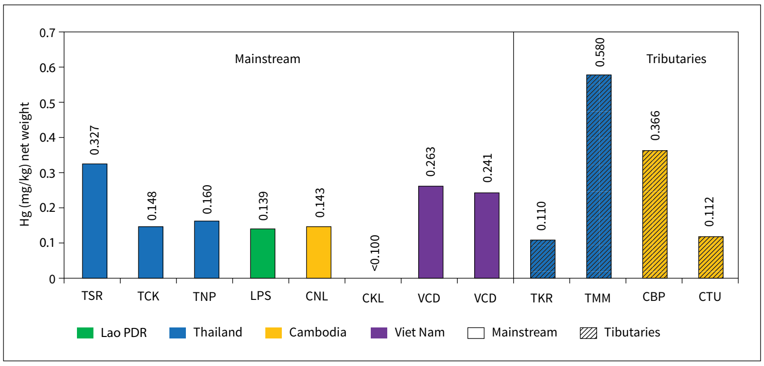
Principle Component Analysis (PCA) was used to analyse heavy metals in carnivorous fish, based on 26 composite samples from16 stations.

Only stations that analysed for heavy metals in carnivorous fish were used (16 out of 28 stations). These included 11 mainstream stations: namely Sob Rouak (TSR), Luang Prabang (LPB), Vientiane (LVT), Pakse (LPS), Kratie (CKT), Neak Loung (CNL), Koh Khel (CKL), Chau Doc (VCD), Tan Chau (VTC), Can Tho (VCT) and My Thuan (VMT) and 5 tributary stations; namely Kok River Mouth (TKR), Xe Bang Fai (LFB), Sekong River mouth (CSR), Back Prea (CBP) and Phnom Penh Port (CPP).

It should be noted that in this treatment if the value is less than the detection limit, the average value is used. If one station is missing, that variable will be taken off automatically. Station names are indicated and categorised into 4 different sections of the LMB (upper, central, lower and Tonle Sap) with the following codes:

- **B1-Station code**
  Station on Mekong River Section 1 – upper part of the LMB (Stations 1–9)
- **B2-Station code**
  Station on Mekong River Section 2 – central part of the LMB (Stations 10–17)
- **B3-Station code**
  Station on Mekong River Section 3 – lower part of the LMB (Stations 18, 21–28)

Figure 3-36: Comparison of heavy metal in mollusc tissue in the Mekong River mainstream and tributaries.



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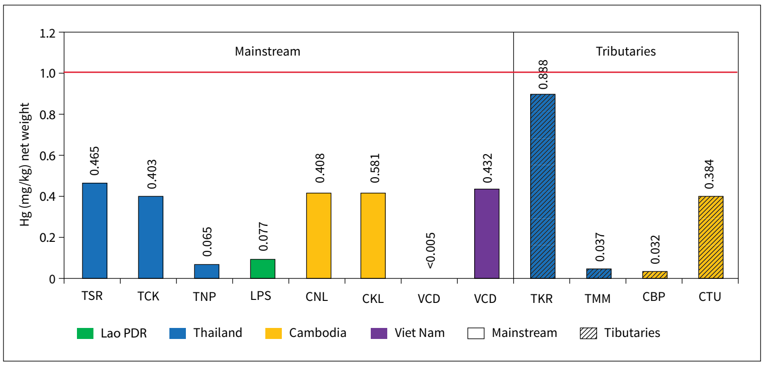
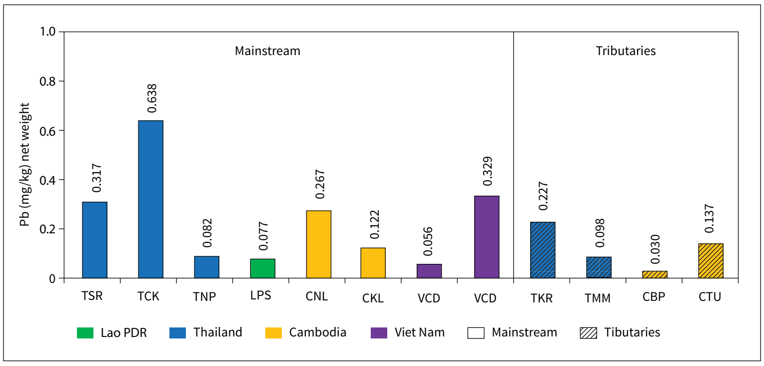


b



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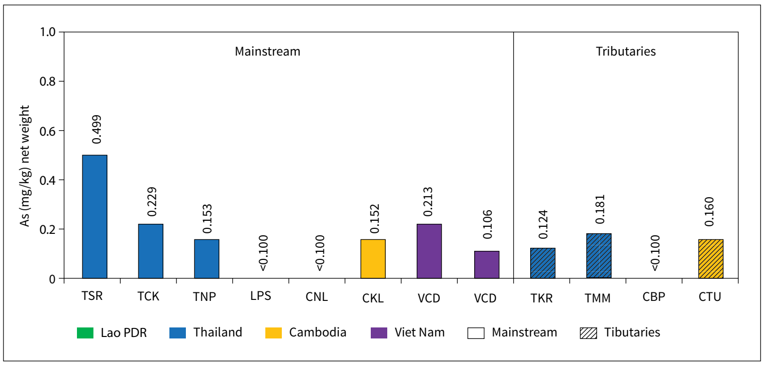

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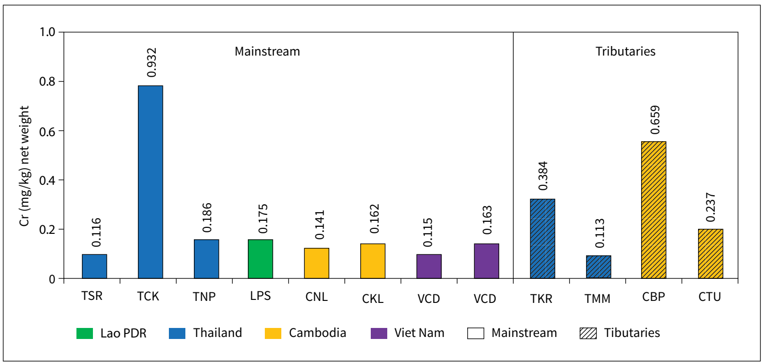
Figure 3-36cont.: Comparison of heavy metal in mollusc tissue in the Mekong River mainstream and tributaries.



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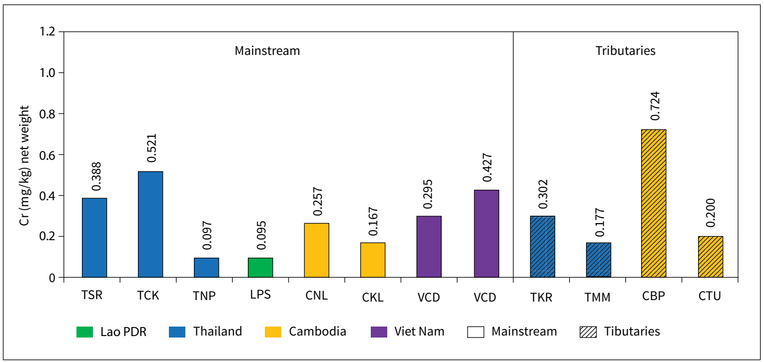

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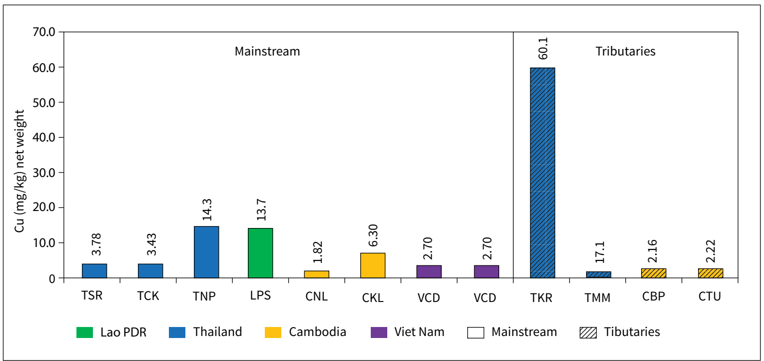


g

- **B4-Station code**

  Station on Tonle Sap Sub-section (Stations 19–20).

The PCA loading score plot of the MMMAP stations for metal contamination in carnivorous fish is shown in Figure 3-35.

With regard to metal contamination, most of the variance of heavy metals was explained by 2 components (Table 3-30 and Figure 3-35). Component 1 (PC1), which represented the variation of Cr and Ni, accounted for 72.6% of the total variance and component 2 (PC2), which represented only the variation of Cu, accounted for 12.6% of total variance.

The two groups can be separated as seen in Figure 3-35. There is no obvious effect of river section on accumulation of heavy metal which indicates that there are no obvious differences in metal contamination within the region.

3.3.2 MOLLUSCS

3.3.2.1 Heavy metals

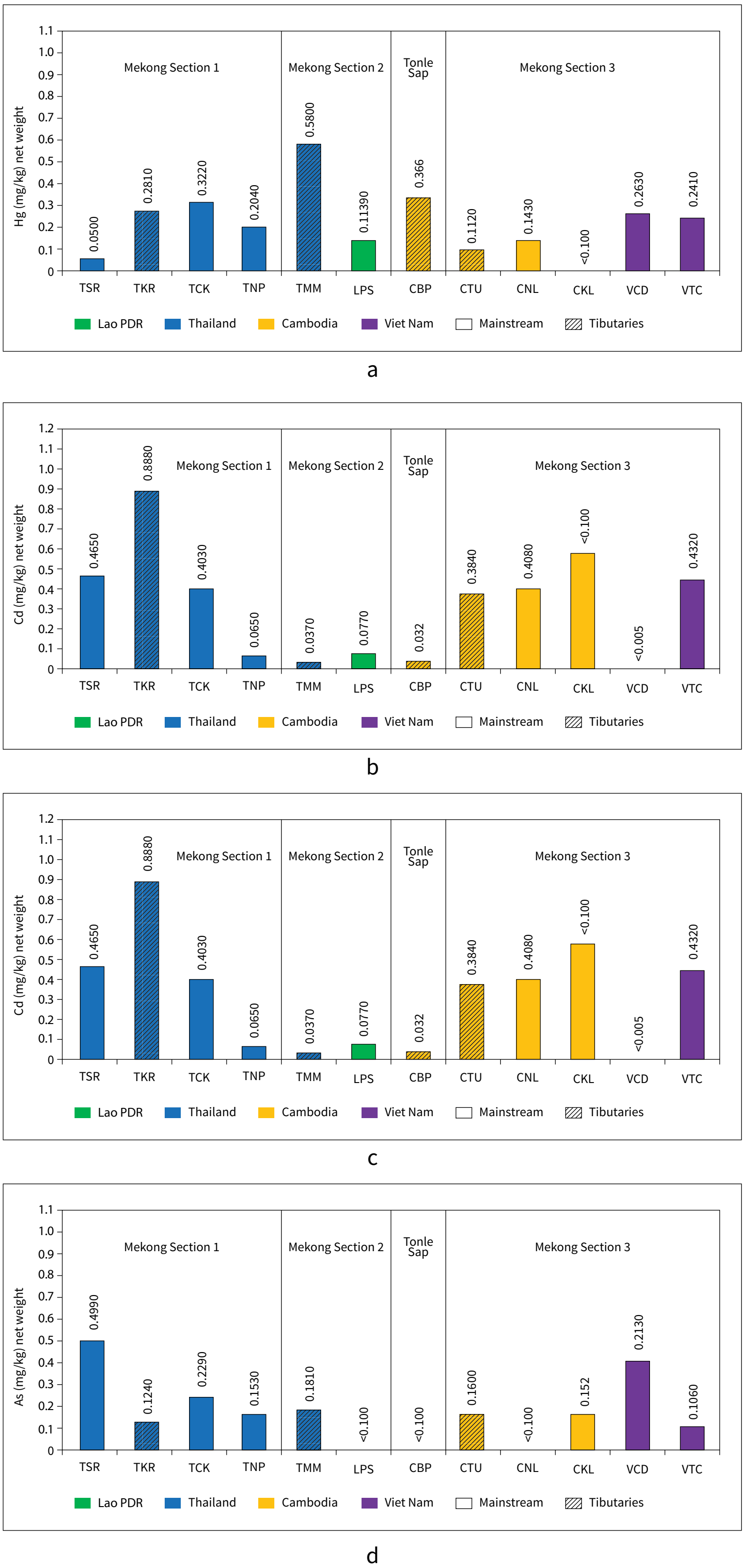
The heavy metals accumulated in mollusc tissue are presented in Tables 3-31 and 3-32 and Figures 3-36 and 3-37. The heavy metal data from other studies are provided for comparison.

Guidelines are available for two heavy metals in mollusc tissue (Cd and Pb). This study (Tables 3-31 and 3-32) found that Cd and Pb accumulated in mollusc tissue at all stations were below the standard (1 mg/kg Cd of EU 2006 and CODEX and 1.5 mg/kg

Table 3-31: Range (minimum – maximum) and average (± s.d.) of heavy metals in mollusc tissue in the Mekong River mainstream, tributaries and other studies.

Parameter	Hg (mg/kg) wet weight	Cd (mg/kg) wet weight	Pb (mg/kg) wet weight	As (mg/kg) wet weight	Cr (mg/kg) wet weight	Ni (mg/kg) wet weight	Cu (mg/kg) wet weight
THIS STUDY							
Mekong River Mainstream							
Min – Max	<0.100-0.327	<0.005-0.581	0.056-0.638	<0.100-0.499	0.115-0.932	0.095-0.521	1.820-14.300
Avg ± SD	0.184±0.087	0.304±0.220	0.236±0.197	0.182±0.144	0.249±0.277	0.281±0.157	6.116±5.038
Tributaries							
Min – Max	0.110-0.580	0.032-0.888	0.030-0.227	<0.100-0.181	0.113-0.659	0.177-0.724	1.710-60.100
Avg ± SD	0.292±0.227	0.335±0.404	0.123±0.082	0.129±0.058	0.348±0.235	0.351±0.255	16.548±29.036
OTHER STUDY							
Mae Klong River, Thailand (Sumritdee, 2007)		0.33	55.83		6.25	0.88	780.88
Ping River, Thailand (Theerapunsatien, 1994)		3.6-5.56					
STANDARD							
EU 2006	1	-	-	-	-	-	-

Figure 3-37: Comparison of heavy metal in mollusc tissue in the Mekong River Sections 1, 2, 3 and Tonle Sap.



Pb of EU 2006). These results indicate that Cd and Pb contamination of molluscs in the Mekong River is at a safe level.

Due to less available data for heavy metals accumulated in freshwater molluscs, some selected studies in Mae-Klong and Ping River in Thailand were used for comparison (Tables3-31) . For the golden apple snail in the Mae-Klong River (Sumritdee, 2007), heavy metal accumulation is reported as 0.88 µg/g of Ni, 0.33µg/g of Cd, 780.88 µg/g of Cu, 55.83 µg/g of Pb and 6.25 µg/g of Cr. A study of the freshwater pearl mussel (Theerapunsatien, 1994) found Cd accumulated at 3.6 to 5.56 µg/g in the Ping River. The results indicate that the risk of contamination to people consuming molluscs from the Mekong River is low.

3.3.2.1.1 Organic Micro-Pollutants

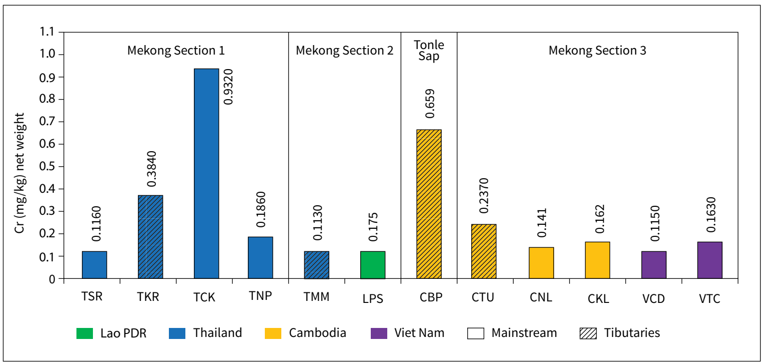
The results for organic micro-pollutants accumulated in mollusc tissue are presented in Tables 3-33 and 3-34. Data from other studies are provided for comparison.

Unfortunately, guidelines for PCBs, HCB and total organochlorine pesticides, such as DDT, endrin, chlordane etc. accumulated in mollusc tissue are not available. The 12 compounds of organic micro-pollutants and groups accumulated in mollusc tissue from Mekong River species in this study were well below the detection limits (Table 3-33 and Table 3-34). The detection limit of 0.1 mg/kg PCBs used in this study is higher than other studies.

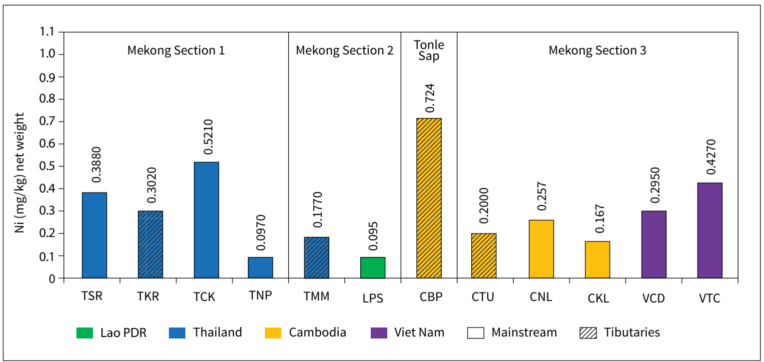
Table 3-32: Range (minimum – maximum) and average (± s.d.) of heavy metal in mollusc tissue in the Mekong River Sections 1, 2, 3 and Tonle Sap.

Parameter	Hg (mg/kg) wet weight	Cd (mg/kg) wet weight	Pb (mg/kg) wet weight	As (mg/kg) wet weight	Cr (mg/kg) wet weight	Ni (mg/kg) wet weight	Cu (mg/kg) wet weight
THIS STUDY							
Mekong Section 1							
Min – Max	0.110-0.327	0.065-0.888	0.082-0.638	0.124-0.499	0.116-0.932	0.097-0.521	3.430-60.100
Avg ± SD	0.186±0.096	0.455±0.338	0.316±0.235	0.251±0.171	0.405±0.370	0.327±0.178	20.403±26.941
Mekong Section 2							
Min – Max	0.139-0.580	0.037-0.077	0.077-0.098	<0.100-0.181	0.113-0.175	0.095-0.177	1.710-13.700
Avg ± SD	0.360±0.312	0.057±0.028	0.088±0.015	0.141±0.057	0.144±0.044	0.136±0.058	7.705±8.478
Mekong Section 3							
Min – Max	0.366	0.032	0.030	<0.100	0.659	0.724	2.160
Avg ± SD	0.366	0.032	0.030	<0.100	0.659	0.724	2.160
Tonle Sap							
Min – Max	<0.100-0.263	<0.005-0.581	0.056-0.329	<0.100-0.213	0.115-0.237	0.167-427	1.820-6.300
Avg ± SD	0.162±0.089	0.451±0.089	0.182±0.112	0.136±0.061	0.164±0.045	0.269±0.101	3.188±1.790
OTHER STUDY							
Mae Klong River, Thailand (Sumritdee, 2007)		0.33	55.83		6.25	0.88	780.88
Ping River, Thailand (Theerapunsatien, 1994)		3.6-5.56					
STANDARD							
EU 2006	1	-	-	-	-	-	-

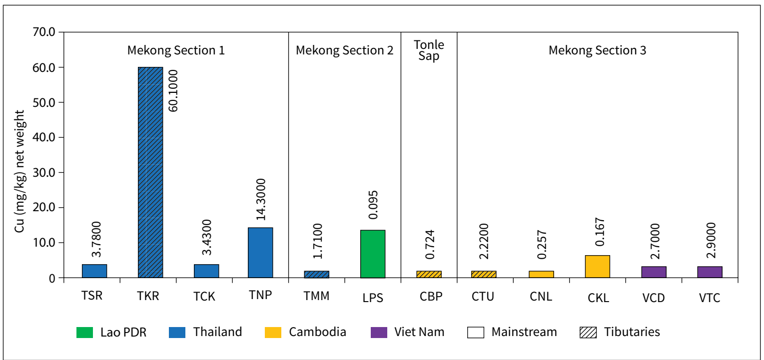
Figure 3-37cont: Comparison of heavy metal in mollusc tissue in the Mekong River Sections 1, 2, 3 and Tonle Sap.



e



f



g

3.3.2.2 Multivariable analysis of mollusc samples (heavy metal contamination)

Multivariable analysis of heavy metals in molluscs was treated by Principle Component Analysis (PCA) based on 12 composite samples from 12 stations.

Only stations that analysed for heavy metals in molluscs were used (12 out of 28 stations). These include 8 mainstream stations: Sob Rouak (TSR), Chiang Khong (TCK), Nakhon Phanom (TNP), Pakse (LPS), Neak Loung (CNL), Koh Khel (CKL), Chau Doc (VCD) and Tan Chau (VTC), and 4 tributary stations namely Kok River mouth (TKR), Khong Chiam (TMM), Back Prea (CBP) and Prek Kdam (CTU).

It should be noted that in this treatment if the value is less than the detection limit, the average value is used. If one station is missing, that variable will be excluded automatically. Station names are indicated and categorised into 4 different sections of the LMB (upper, central, lower and Tonle Sap) with the following codes:

- **B1-Station code**
  Station in Mekong River Section 1 – upper part of the LMB (Stations 1–9)
- **B2-Station code**
  Station in Mekong River Section 2 – central part of the LMB (Stations 10–17)
- **B3-Station code**
  Station in Mekong River Section 3 – lower part of the LMB (Stations 18, 21–28)
- **B4-Station code**
  Station in Tonle Sap Sub-section (Stations 19–20).

Table 3-33: Range (minimum – maximum) and average (± s.d.) of organic micro-pollutants in mollusc tissue in the Mekong River mainstream and tributaries.

Parameter	Total PCB (mg/kg wet weight)	Hexachloro benzene (HCB) (mg/kg wet weight)	Total Organochlorine Pesticide									
			p̦ p' -DDT (mg/kg wet weight)	p̦ p' -DDE (mg/kg wet weight)	p̦ p' -DDD (mg/kg wet weight)	Endrin Aldehyde (mg/kg wet weight)	Endosulfan Sulfate (mg/kg wet weight)	Heptachlor (mg/kg wet weight)	Heptachlor Epoxide (mg/kg wet weight)	α-Hexachloro Cyclohaxane (mg/kg wet weight)	γ-Hexachloro Cyclohaxane (mg/kg wet weight)	Chlordane (CHL) (mg/kg wet weight)
THIS STUDY												
Mekong River mainstream												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Tributaries												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1

Table 3-34: Range (minimum – maximum) and average (± s.d.) of organic micro-pollutants in mollusc tissue in the Basin 1, 2, 3 and Tonle Sap.

Parameter	Total PCB (mg/kg wet weight)	Hexachloro benzene (HCB) (mg/kg wet weight)	Total Organochlorine Pesticide									
			p,p’-DDT (mg/kg wet weight)	p,p’-DDE (mg/kg wet weight)	p,p’-DDD (mg/kg wet weight)	Endrin Aldehyde (mg/kg wet weight)	Endosulfan Sulfate (mg/kg wet weight)	Heptachlor (mg/kg wet weight)	Heptachlor Epoxide (mg/kg wet weight)	α-Hexachloro Cyclohaxane (mg/kg wet weight)	γ-Hexachloro Cyclohaxane (mg/kg wet weight)	Chlordane (CHL) (mg/kg wet weight)
THIS STUDY												
Mekong Section 1												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Mekong Section 2												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Mekong Section 3												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Tonle Sap												
Min – Max	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
Avg ± SD	<0.1	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.1
OTHER STUDY												
Mekong River In Delta Viet Nam (F.P.Carvalho, 2008)	0.0004-0.003	0.00001-0.00004	0.001-0.023									

Remarks
Section 1 = Stations 1 to 9 (9 Stations)
Section 2 = Stations 10 to 17 (8 Stations)
Section 3 = Stations 18, 21 to 28 (9 Stations)
Tonle Sap = Stations19 and 20 (2 Stations)

The PCA loading score plot of the MMMAP stations for metal contamination in mollusc sample is shown in Figure 3-38.

With regard to metal contamination, most of the variance of heavy metals was explained by 2 components (Table 3-35 and Figure 3-38). Component 1 (PC1), which represented the variation of Cr and Ni, accounted for 91.2% of the total variance. Component 2 (PC2), which represented only the variation of Cu, accounted for 4.8% of total variance.

The two groups can be separated as seen in Figure 3-38. The accumulation of metal in molluscs in the LMB has no obvious control by river section, which implies that there are no obvious differences in metal contamination within the region.

3.3.3 MULTIVARIABLE ANALYSIS OF LINKS BETWEEN THREE MEDIA (WATER, SEDIMENT AND BIOTA)

To understand the correlation between water, sediment and biota, this study attempted to analyse the relation by PCA.

It should be noted that in this treatment if the value is less than the detection limit, the average value is used. If one station is missing, that variable is automatically excluded. Station names are indicated and categorised into 4 different sections of the LMB (upper, central, lower and Tonle Sap) with the following codes:

- **B1-Station code**
  Station on Mekong River Section 1 – upper part of the LMB (Stations 1–9)

Figure 3-38: PCA loading score plot of mollusc sampling at all stations by regions for heavy metal parameters.

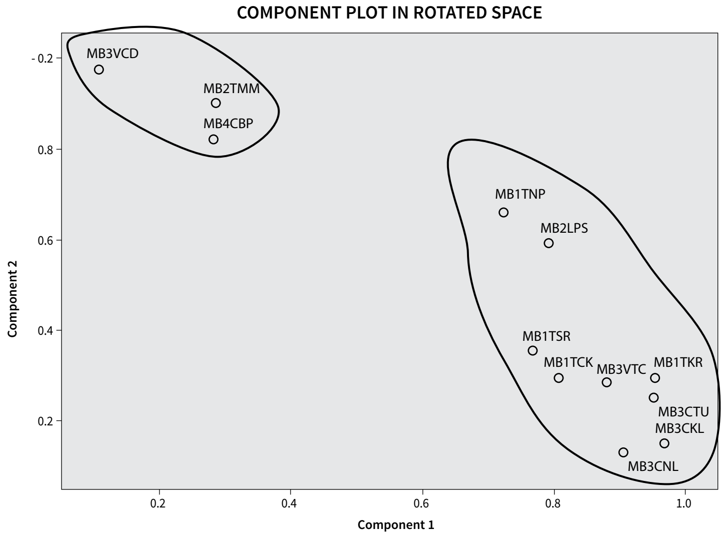


Table 3-35: Rotated component matrix of heavy metal parameters in mollusc samples.

Variables	Component	
	1	2
Hg	-0.05	-0.48
Pb	0.64	-0.03
As	0.04	-0.12
Cr	0.95	0.10
Ni	0.81	-0.28
Cu	-0.06	0.99
% Cumulative	91.2	4.8

- **B2-Station code**
  Station on Mekong River Section 2 – central part of the LMB (Stations 10–17)
- **B3-Station code**
  Station on Mekong River Section 3 – lower part of the LMB (Stations 18, 21–28)
- **B4-Station code**
  Station on Tonle Sap Sub-section (Stations 19–20)

The PCA loading score plot of the MMMAP stations for metal parameters in all media (water, sediment and biota) is shown in Figure 3-39.

Figure 3-39: PCA loading score plot of 3 media at all stations by regions for heavy metal parameters.

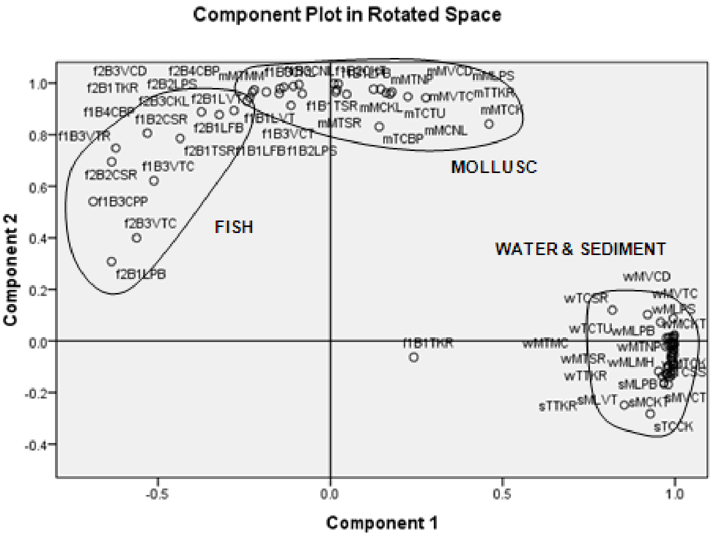


Table 3-36: Rotated component matrix for heavy metals.

Variables	Component	
	1	2
Hg	-0.49	-0.09
Pb	0.98	-0.20
As	-0.02	0.08
Cr	0.97	0.07
Ni	0.97	0.13
Cu	0.50	0.69
% Cumulative	90.6	4.2

With regard to metal contamination, most of the variance in heavy metals was explained by 2 components (Table 3-36 and Figure 3-39). Component 1 (PC1), which represented the variation of Pb, Cr and Ni, accounted for 90.6% of the total variance. Component 2 (PC2), which represented only the variation in Cu, accounted for 4.2% of total variance.

From the PCA result, the variation in heavy metal data in sediment and water is related, particularly for Pb, Cr and Ni. The biota group can be separated into subgroups (Figure 3-39). The fish group is closely related to component 2, while the mollusc group is more related to component 1 than the fish group. The mollusc group is also closer to water and sediment media than the fish group. This suggests that the uptake of Pb, Cr and Ni by molluscs from water and sediment was higher than for fish.

The clear separation between each media indicates that biota, including fish and molluscs, are not only taking up metals directly from water and sediment; but may also be taking up metals from other sources such as food.

4. OVERALL STATUS & TRENDS

4. OVERALL STATUS & TRENDS

The 2011 MMMAP attempted to update the status of water quality in the Lower Mekong Basin with a focus on persistent pollutants. It also identified the level of concern for environmental quality at locations sampled in the Mekong mainstream and tributaries not only in water, but also for sediments and biota. Information used to evaluate the environmental condition of the Lower Mekong River mainstream and tributaries included: (i) primary data from analytical results for water, sediment and biota sampled during 2011 in comparison with water quality monitoring data from previous MRC studies and other relevant studies; and (ii) updated information on human activities and development pressures which generate point source and non-point source pollution in relation to updated monitoring data from this study. The study provided an overall assessment of the status of water quality and environment in terms of the relation between pollution sources and actual presence of pollutants in the Lower Mekong Basin.

Where possible, water, sediment and biota quality were evaluated in relation to existing relevant guidelines and/or criteria. For surface water, the chosen comparisons are MRC criteria and target value for the protection of aquatic life (WQCA) and criteria and target value for the protection of human health (WQCH), For sediment, the chosen standards are ANZECC lowland and upland river low-high criteria. For biota, the FDA/EPA guidelines, CODEX standards and EU2006 guidelines have been applied.

The parameters used to evaluate environmental conditions in the Mekong mainstream and tributaries include the following:

- For surface water, the general parameters and nutrients (28 stations), heavy metals (21 stations), pesticide and toxic substances (21 stations) were analysed. The total numbers were 943 parameters, of which 4.1% exceeded the criteria for protection of human health (WQCH).
- For sediment, heavy metals and pesticides were analysed from 27 stations. The total numbers were 453 parameters, of which 9.9% of total parameters exceeded ANZECC Upland River guidelines.
- For biota, heavy metals and pesticides in fish tissue (17 stations) and mollusc tissue (12 stations) were analysed. The total numbers were 893 parameters, none of the sampling stations exceeded FDA/EPA, CODEX or EU2006 guidelines.

It is quite complicated to identify the dominant sources and/or indicate close relationship between monitoring results of each parameter and source of contamination. However, according to the summarised information, elevated values of some parameters in each station and overall trends can be generally discussed.

4.1 POLLUTION DISTRIBUTION AND POSSIBLE SOURCES

Due to the vast extent of the LMB geography and landscapes, the study categorised sampling locations into 4 regions, called sub-basin 1, 2, 3 and 4, based on sampling stations detailed in chapter 3. Notwithstanding the research team's best efforts to collect and review primary and up-to-date pollution source information in MRC member countries and the region, the availability of published information of pollution sources is very limited. The sources of pollution identified and estimated in this study are partly based on other earlier reviews and primary information from MRC member countries. A summary of pollution sources for each location is given below.

4.1.1 MEKONG SECTION 1 (UPPER SUB-BASIN: MONITORING STATIONS 1–9)

The river tributaries of the Upper Mekong Basin in the Yunnan Province of China are narrow. In the Northern Highlands, the river is wider, where large tributaries enter through the left and right banks of the Mekong River. Sub-basin 1 is classified as the upper part of the Lower Mekong Basin (LMB) highland areas. Sub-basin 1 is composed of 11 sub-basins: Nam Nuao, Nam Mae Kok, Nam Khan, Nam Khop, Nam Phuong, Nam Nhiep, Huao Bang Bot, Nam Phone, Nam Theun, Phu Pa Huak and Huai Thuai, located in Lao PDR and Thailand. The total area of the sub-basin is 213,575 km^2. The hilly and mountainous landscape means that most of the area in this basin is forest; only 24% is farmed under lowland terrace or upland shifting cultivation.

As elsewhere in the sub-basin, conversion of land to agriculture, road construction and logging has steadily reduced forest cover. The consequences are losses of soil fertility and crop yield, accelerated erosion on hill slopes and higher sediment delivery to streams (Chaplot et al., 2005). An increase of sediment, which carries nutrients and minerals downstream has negative impacts on the livelihoods and health of downstream populations. In addition, activities related to high economic growth in this sub-basin have also been noted, such as the rapid development of the hydropower and mining sectors (World Bank, 2008). More than 570 mineral deposits have been identified, including gold, copper, zinc, lignite and lead (DOG, 2009).

Based on the review of pollution in the sub-basin, the following is a summary of dominant point and non-point sources.

Point sources:

- Using the 2007 MRC GIS data, the total population is estimated to be approximately 11,281,609 people, with an average population density of about 53 person/km^2, the highest population density was observed in Huai Thuai (198 person/km^2).
- Examples of tourist areas in this sub-basin are Luang Prabang and Chiang Rai.
- Many dams are either operating or

under construction, such as Nam Theun, Theun-Hinboun, Nam Nguem, Nam Leuk, Nam Lik and Houay Ho in Lao PDR. The development of hydropower is expected to expand in future.

- An estimate of pollutant loading is about 123,534 ton/year of BOD, 32,942 ton/year of Total-N and 9,883 ton/year of Total-P. This estimate is based on the number of total population in 2007 and provincial reports in 2010–2011. Huai Bang Bot has the greatest urban population.

Non-point sources:

- Based on the rice field area of approximately 50,357 km^2, fertiliser inputs are estimated as 327,410 ton/year of total-N. The total-N loss is about 31,594 ton/year. The estimated annual pesticide use is 10,544 ton/year for rice and 10,530 ton/year for 'non-rice' fields, based on the total non-rice field area of 10,530 km^2.
- In many parts of the country, exploration, planning and actual mining are underway. Gold mineral is the major resource in this sub-basin. Mining uses a lot of water during both the mining and ore processing stages. However, very little information is available regarding the amount of water used.
- Large port and intensive transportation at Chaing Saen 1 and Chiang Sean 2 (planned to start operation in 2012) which are located at the mouth of the Kok River.

According to the current monitoring results, elevated parameters and overall trends and status of water, sediment and biota are summarised below.

Surface water:

- Physiochemical and conventional parameters
  - According to Table 3-2 (Chapter 3), monitoring results of almost all physicochemical and conventional parameters in the Mekong Section 1 complied with the water quality criteria.
  - Same range of pH values was observed with only small variation.
  - Water temperature gradually increases from 24°C at the LMH with the distance downstream.
  - Elevated conductivity was noted at TSR and LVT stations, possibly due to domestic impacts from Nam Mae Kok and Nam Phoung sub-basin, respectively.
  - High and over-saturated DO values were found at several stations of Mekong Section 1, indicating good quality water and for some over-saturation, mainly caused by strong and rapid flow of the river during the sampling period.
  - All BOD values in Mekong Section 1 complied with the water quality criteria indicating good water quality in terms of BOD.
  - COD values exceeded the current water quality guidelines, since the WQCH threshold is as low as 5 mg/L. The elevated COD values in the Mekong Section 1 were found at TKR and LPB stations, mainly indicating impacts of human activities from Nam Mae Kok and Nam Khan sub-basins, respectively.

- SS concentrations in Mekong Section 1 upstream, were much higher than other sections and Tonle Sap system due to high river water flow in rainy season and heavy rain causing sediment runoff. The elevated SS values were found at TKR and LPB stations, due to turbulent flows at the Kok River mouth before joining the Mekong mainstream and high river flow from the heavy rain, respectively.
- Elevated values of oil and grease (O&G) were found at LPB and LVT stations, possibly caused by high navigation activities as well as heavy rain during sampling.
- The highest TDP concentration was found at LMH in Nam Nuao sub-basin, suggesting an upper Mekong source and possible transboundary pollution from Yunnan province of PR China.

- Dissolved and particulate heavy metals
  - Concentrations of dissolved metals, bio-available fraction, did not exceed the threshold limit (Table 3-4) at any stations of Mekong Section 1 and, in fact, were well below the threshold.
  - In general, dissolved lead levels were slightly higher in the upstream, Mekong Section 1, than in the downstream.
  - Higher dissolved arsenic values were noticed in the upstream section and fell downstream.
  - Dissolved copper concentrations show a trend of decreasing downstream, while particulate copper shows an increasing trend toward downstream.

- Organic micro-pollutants
  - Cyanide and phenols were the only two groups of micro-pollutants detected in this study (Table 3-8).
  - All cyanide concentrations exceeding the guideline were found in Mekong Section 1, located in the same catchment area: TMC, TKR and TCK stations, Nam Mae Kok sub-basin. A possible source of cyanide is pesticides applied to plantations in the area.
  - Phenol concentrations at several stations: TMC, TKR and TCK in Nam Mae Kok sub-basin, and LVT in Nam Phuong sub-basin, exceeded the guideline levels. These high values might be due to leakage of petroleum products from nearby cities or navigation activities.

Sediment:

- Heavy metals
  - Arsenic and copper concentrations did not exceed the ANZECC upland river threshold in Mekong Section 1 (Table 3-11). Cadmium concentrations were below the detection limits as well as far below the ANZECC upland river threshold. Only mercury concentrations at some stations were higher than the ANZECC upland river threshold but within the lowland threshold. However, lead concentrations at some stations exceeded the ANZECC lowland threshold.
  - Mercury values exceeded the upland river threshold at TSK and TCK stations, in Nam Mae Kok sub-basin, possibly due to domestic sources as

well as other human activities, namely the port.
  - Lead concentrations exceeded the upland river threshold at all stations and at LMH and TMC the concentrations were even higher than the lowland river threshold.

Biota:

- Fish and molluscs
  - As demonstrated in Table 3-24 and 3-29 (Chapter 3), no heavy metal concentrations in edible fish tissue exceeded any of the standard thresholds, namely EU 2006, CODEX, and FDA/EPA, while the micro-pollutant concentrations in fish tissue were lower than detection limits for all stations.
  - Similarly, no heavy metal concentrations in mollusc tissue exceeded any of the standard thresholds, namely EU 2006 and CODEX (Tables 3-32 and 3-34), while the micro-pollutant concentrations in mollusc tissue were lower than detection limits for all stations.

4.1.2 MEKONG SECTION 2 (CENTRAL SUB-BASIN: MONITORING STATIONS 10 TO 17)

Sub-basin 2 is located in the middle of the LMB. It includes 7 sub-basins: Nam Chi, Huai Som Pak, Nam Mun, Huai Tomo (3Ss), Huai Khanouan, Tonle Ropov and Prek Chlong, in northeast Thailand, Lao PDR, and Cambodia. The total area is 269,058 km^2. This is an area of gently rolling hills set amid relatively flat plains. Soils and deciduous vegetation on the hills are thin, and much of the original forest has been replaced by agricultural land (www.history.com) The major sub-basins are the Mun, Chi and Sekong, Sesan, and Srepok (3Ss) catchments. Irrigated agriculture and fishing are important resources. In the central plateau, urban areas and communities have been growing rapidly, such as in Pakse, Ubon Ratchathani and Kratie. Industrial areas have expanded in the Nam Chi sub-basin in Thailand. Many dams and reservoirs have been constructed and operated, especially in Huai Tomo (3Ss). Moreover, expansion of large-scale hydropower is expected in the tributary basins of the 3Ss, covering parts of Lao PDR, Cambodia and Viet Nam (Xue et al., 2011).

A review of pollution gives the following summary of dominant point and non-point sources:

Point sources:

- Using the MRC GIS data for 2007, the total population is estimated to be approximately 22,608,951 people, with average population density about 84 person/km^2. The highest population density was observed in Nam Mun (141 person/km^2).
- Examples of tourist areas in this sub-basin are Loei, Ubon Ratchathani, Udonthani, Nong Kai, and Vientiane.
- Large-scale hydropower dams were constructed in Nam Chi, Huai Som Pak and 3Ss sub-basins, such as Sirinthorn, Chulaphorn, and Sexet 1, 2, 3. Moreover, 45 different dams have been proposed for the 3Ss Basin: 22 dams on Sekong, 13 dams on Sesan and 10 on Srepok.

- 7,500 factories are operating in the Nam Chi sub-basin, mainly automobile and textile industries.
- An estimation of pollutant loading is approximately 185,951 ton/year of BOD, 65,737 ton/year of Total-N, and 19,721 ton/year of Total-P, based on the total number of population in 2007 and provincial reports in 2010–2011. Nam Mun has the largest urban population.

Non-point sources:

- Based on a rice field area of approximately 112,234 km^2, fertilizer inputs are expected of 1,052,610 ton/year of total-N. The total-N loss is around 80,545 ton/year. The estimated annual pesticide used in this sub-basin is 32,869 ton/year for rice fields, and 26,580 ton/year for non-rice field, based on a total non-rice field area of 26,580 km^2.
- Gold and bauxite-aluminum minerals are the largest and most valuable resources in this sub-basin. Mining activities consume a lot of water in both mining and ore processing stages. However, very little information is available regarding the amount of water use.

Based on the monitoring results, a summary of elevated parameters and overall trend and status of water, sediment and biota is given below.

Surface water:

- Monitoring results of almost all physico-chemical and conventional parameters in Mekong Section 2 complied with the water quality criteria (Table 3-2).
- Same range of pH values was observed at all stations.
- Water temperatures were quite similar at all stations.
- Elevated conductivity was noted at TMM station, possibly due to various human activities in the Nam Mun sub-basin.
- High DO values were found at several stations of Mekong Section 2, indicating good quality.
- BOD value higher than WQCH guideline was found at LPS station, near Pakse town, possibly caused by domestic impacts from Huai Som Pak sub-basin.
- COD values exceeded the current water quality guidelines, since the WQCH threshold is as low as 5 mg/L. The elevated COD value in the Mekong Section 2, was found at CSP station, mainly indicating the impacts of human activities in the Huai Tomo (3Ss) sub-basin.
- SS concentrations in Mekong Section 2 were in the same range, with no elevated value.
- Elevated values of O&G were found at CMR, CKM, CSP and CSR stations, possibly caused by high navigation activities as well as heavy rain during the sampling time.
- The highest chlorophyll a was found at TMM station. The lowest concentration of SS was found at the same station (Figure 3-7). This could imply that high penetration of light due to the low SS promotes photosynthesis and increases chlorophyll a concentration.
- Dissolved and particulate heavy metals
  - No concentrations of dissolved metals,

bio-available fraction were exceeded at any station and, in fact, all were well below the threshold limit (Table 3-4).

- Organic micro-pollutants
  - Cyanide and phenols were the only two groups of micro-pollutants detected in this study (Table 3-8).
  - The level of phenols found at LPS, Huai Som Pak sub-basin, exceeded the guideline level, due to possible leakage of petroleum products from nearby cities or navigation activities.

Sediment:

- Heavy metals
  - Arsenic and copper concentrations did not exceed the ANZECC upland river threshold; and cadmium concentrations were below the detection limits as well as far below the ANZECC upland river threshold (Table 3-11). Several heavy metal concentrations, namely mercury, chromium and nickel, were higher than the ANZECC upland river threshold but within the lowland threshold. However, lead concentrations at some stations exceeded the ANZECC lowland threshold.
  - Mercury values exceeded the upland river threshold at CSS and CSR stations, in Huai Tomo (3Ss) sub-basin, possibly due to domestic sources as well as other human activities, namely the port.
  - Chromium and nickel concentrations exceeded the upland river threshold at CSP and CSR stations in Huai Tomo (3Ss) sub-basin, probably affected by small communities upstream.
  - – Lead concentrations exceeded the upland river threshold at all stations, except several stations in Mekong Section 2, namely LPS, CKM, CSS, CSP, CSR and CKT stations where the concentrations were even higher than the lowland river threshold.

Biota

- Fish and molluscs
  - No heavy metal concentrations in edible fish tissue exceeded the standard thresholds, namely EU 2006, CODEX, and FDA/EPA, while the micro-pollutant concentrations in fish tissue were lower than detection limits for all stations (Table 3-24 and 3-29).
  - Similarly, no heavy metal concentrations in mollusc tissue exceeded the standard thresholds, namely EU 2006 and CODEX, while the micro-pollutant concentrations in mollusc tissue were lower than detection limits for all stations (Table 3-32 and 3-34).

4.1.3 MEKONG SECTION 3 (LOWER SUB-BASIN: MONITORING STATIONS 18 AND 21–28)

Sub-basin 3 is located in the lower part of the LMB. It includes the Prek Thnot sub-basin in Cambodia and Delta sub-basin in Viet Nam. The total area of the lower sub-basin is 61,773km^2. The Mekong Delta begins near Phnom Penh and ends as a huge fertile plain in southern Viet Nam where the largest tributary, the Bassac River, branches away from the Mekong. This sub-basin is the major agricultural region, farmed intensively with very little remaining vegetation. Forest cover is around 10%. Many settlements occur along the Mekong riverbank. Agricultural expansion and high population density are the major causes of land-use and landscape changes. Several industrial activities are also introducing pollutants that may affect water quality. The river and dense channel networks are major transportation routes in this area.

A review of pollution gives the following summary of dominant point and non-point sources:

Point sources:

- Total population is approximately 21,239,583 people and average population density is around 344 people/km^2. The highest population density was reported in the Delta (356 person/km^2).
- Main industries are food processing with the estimated discharge volume of 13,700 m^3/day (The discharge volume is only from Delta Sub-basin)
- The estimation of loading based on the total number of population in 2007 of Delta and Prek Thnot Sub-basins area is approximately 232,573 ton/year of BOD, 62,020 ton/year of Total-N, and 18,606 ton/year of Total-P. From these estimates, the values were higher in the Delta area.

Non-point sources:

- Based on a rice field area of about 32,943 km^2, fertilizer inputs are estimated as 653,810 ton/year of total-N, 387,020 ton/year of total-P and 290,265 ton/year of total-K. The total-N loss is around 23,004 ton/year. The estimated annual pesticide used in this sub-basin is 16,965 ton/year for rice fields and 1,941 ton/year for non-rice fields.
- A large port and intensive transportation are found at Phnom Pehn Port, where the CPP station is located.

Based on the monitoring results, a summary of elevated parameters and overall trends and status of water, sediments and biota are given below.

Surface water:

- Physicochemical and conventional parameters
  - Monitoring results of almost all physicochemical and conventional parameters in Mekong Section 3 complied with the water quality criteria (Table 3-2).
  - Same range of pH values was observed with only small variation.
  - Water temperatures were not significantly different.
  - Elevated conductivity was noted at VTC station, possibly due to various human activities from the Delta sub-basin.
  - High DO values were found in several stations of Mekong Section 3, indicating good water quality.
  - Slightly lower than the WQCA guideline (5 mg/L) DO was measured at VCT, possibly caused by readily oxidizable organic matter from domestic activity in the area.

- BOD values higher than WQCH guideline were found at CKL, CNL and CTU stations, indicating domestic impacts on water quality in the area.
- COD values were slightly higher or within the current water quality guidelines, except for one elevated value at CPP station. The elevated COD value in the Mekong Section 3 mainly indicated impacts of human activities from Prek Thnot sub-basin.
- SS concentrations in Mekong Section 3 were in the same range, with no elevated value.
- Elevated values of O&G were found at CPP, possibly due to dense communities surrounding the area.

• Dissolved and particulate heavy metals
  - No concentrations of dissolved metals, bio-available fraction, were exceeded at any stations, and, in fact, levels were well below the threshold limit (Table 3-4).
  - The trend for all mercury species (total, reactive, and particulate mercury) were at higher levels in Mekong Section 3, downstream of the LMB.
  - Particulate lead concentrations were elevated in the downstream area, especially in the Mekong Section 3
  - Particulate copper concentrations show an increasing trend toward downstream, while dissolved copper shows the opposite.

• Organic micro-pollutants
  - Cyanide and phenols were the only two groups of micro-pollutants detected in this study (Table 3-8).
  - Phenol concentrations exceeding the guideline levels were found at several stations (CCV and CPP in Prek Thnot sub-basin and VCT in the Delta sub-basin). These high values may be due to leakage of petroleum products from nearby cities or navigation activities.

Sediment:

• Heavy metals
  - Arsenic and copper concentrations did not exceed the ANZECC upland river threshold and cadmium concentrations were below the detection limits as well as far below the ANZECC upland river threshold (Table 3-11). Concentrations of several heavy metals, namely mercury, chromium and nickel, were higher than the ANZECC upland river threshold but within the lowland threshold. However, lead concentrations at some stations exceeded the ANZECC lowland threshold.
  - Mercury values exceeded the upland river threshold at CCV, CTU and CPP stations, in Prek Thnot sub-basin, possibly due to domestic sources as well as other human activities, namely the port.
  - Chromium and nickel concentrations exceeded the upland river threshold at CTU and CPP stations in Prek Thnot sub-basin, probably affected by communities upstream.
  - Lead concentrations exceeded the upland river threshold at all stations and at CCV and CPP stations the con-

centrations were even higher than the lowland river threshold.

Biota:

- Fish and molluscs
  - No heavy metal concentrations in edible fish tissue exceeded the standard thresholds, namely EU 2006, CODEX, and FDA/EPA, while the micro-pollutant concentrations in fish tissue were lower than detection limits at all stations (Tables 3-24 and 3-29).
  - Elevated mercury concentration was observed in one composite sample of yellow catfish, collected at VTC station.
  - No heavy metal concentrations in mollusc tissue exceeded the standard thresholds, namely EU 2006 and CODEX, while the micro-pollutant concentrations in mollusc tissue were lower than detection limits for all stations (Tables 3-32 and 3-34).

4.1.4 TONLE SAP (TONLE SAP SYSTEM: MONITORING STATIONS 19 AND 20)

The Tonle Sap Great Lake, Cambodia, is one of the largest freshwater lakes in Southeast Asia. It forms a natural flood-plain reservoir in the depression of the Cambodian Plain, and the water is drained into the Mekong River near Phnom Penh. When the level of the Mekong River is high, the flow of the Tonle Sap River is reversed and water is pushed into the lake. The soils are mainly developed in the unconsolidated alluvial deposits, comprising clay, silt, sand, and gravel. The total area of this sub-basin is approximately 85,138 km^2. Development of tourism has been encouraged in places such as Siem Reap, Kampong Thom, and Preah Vihear. Activities in the Tonle Sap area are mainly based on fisheries or agriculture. Fish processing is widespread, while agriculture is focused on rice production in most places. Infrastructure facilities are largely absent, particularly in the floating or stilted villages.

A review of pollution gives the following summary of dominant point and non-point sources:

Point sources:

- According to the 2007 MRC GIS data, the total population is estimated to be approximately 5,666,537 people with an average population density of about 67 people/km^2.
- An example of tourism in the Tonle Sap Lake are the tourist cruises on the Great Lake.
- Only small-scale hydropower has been developed.
- An estimation of pollutant loading is about 62,049 ton/year of BOD, 16,546 ton/year of Total-N and 4,964 ton/year of Total-P, based on the total population number in 2007.

Non-point sources:

- Based on a rice field area of approximately 24,075 km^2, fertilizer inputs are estimated as 182,930 ton/year of total-N. The total-N loss is about 17,483 ton/year. The estimated annual pesticide used in this sub-basin is 6,922 ton/year for rice fields and 3,358 ton/year for non-rice fields, based on a total non-rice field area of 3,358 km^2.

- Aquaculture has been noticed, especially the crocodile farm in Stoeng, Sangke Province.

Based on the monitoring results, a summary of elevated parameters and overall trends and status of water, sediments and biota are summarised below:

Surface water:

- Monitoring results for almost all physicochemical and conventional parameters in the Tonle Sap system complied with water quality criteria (Table 3-2).
- The same range of pH values was observed at all stations.
- Water temperatures were quite similar at all stations (about 32°C).
- The same range of conductivity was found in this area.
- A DO value slightly lower than the WQCA guideline (5 mg/L) was measured at CBP station, possibly due to readily oxidizable organic matter from domestic activities in the area.
- A slightly high BOD value – higher than the WQCA guideline – was found at CCK station, potentially due to impacts from domestic activities in the Great Lake area.
- COD values exceeded the water quality guidelines (WQCH threshold of 5 mg/L). The elevated COD values in the Tone Sap system were found in both CBP and CCK, mainly indicating impacts of human activities from Tonle Sap sub-basin.
- SS concentrations were in the same range throughout the Tonle Sap system, with no elevated value.
- Elevated chlorophyll a concentrations at CCK station, in the Great Lake, were likely attributable to drainage water from the surrounding area and a longer residence time of water within the lake.

Sediment:

- Heavy metals
  - Arsenic and copper concentrations did not exceed the ANZECC upland river threshold; and cadmium concentrations were below the detection limits as well as far below the ANZECC upland river threshold (Table 3-11). Several heavy metal concentrations, namely mercury, chromium, nickel and lead, were higher than the ANZECC upland river threshold but within the lowland threshold.
  - Mercury values exceeded the upland river threshold at CCK station, possibly caused by domestic sources as well as other human activities, namely the port.
  - Chromium and nickel concentrations exceeded the upland river threshold at both stations in the Tonle Sap system (CBP and CCK), probably due to communities upstream.

Biota:

- Fish and molluscs
  - No heavy metal concentrations in ed-

ible fish tissue exceeded the standard thresholds, namely EU 2006, CODEX, and FDA/EPA, while the micro-pollutant concentrations in fish tissue were lower than detection limits for all stations (Tables 3-24 and 3-29).

- No heavy metal concentrations in mollusc tissue exceeded the standard thresholds, namely EU 2006 and CODEX, while the micro-pollutant concentrations in mollusc tissue were lower than detection limits for all stations (Tables 3-32 and 3-34).

4.2 CLASSIFICATIONS OF WATER, SEDIMENT AND BIOTA IN THE LMB

The MMMAP was conducted to investigate the quality of water, sediment and biota in the Lower Mekong River basin. The colour code is proposed as an alternative to classify the status of water quality according to this monitoring program. Each medium is given a different colour classification based on the different parameters and guidelines applied. For surface water, the water quality results were compared with both MRC WQCA and WQCH guidelines, and classification was made based on the number of exceedance. This is in contrast to normal practice where water quality index (WQI) is used for classifying surface water quality, and therefore, it should be noted that the classifications used in this report is different from the MRC Water Quality Indices where a well developed arithmetic has been adopted to classify water quality based on different uses (human impact, protection of aquatic life, and agricultural use).

For sediment quality, the index of geo-accumulation technique is used. Although all normalisation methods in this study – considering co-factors (Al or Li), enrichment factor (EF), and index of geo-accumulation (Igeo) – provided results for sediment contamination in the same direction, the Igeo is the least complicated. The biota quality guideline, heavy metal residues in fish and mollusc tissue (products), are generally aimed to protect consumers of fish and molluscs. These guidelines are issued by various organisations. The European Commission 2006 standard was selected as it contains more heavy metal parameters than others (Table 2-7).

The colour code classification proposed is based on the monitoring results from this single study. The colours were used solely for the purpose of grouping stations to better understand the current status in the LMB.

4.2.1 SURFACE WATER

Evaluations of surface water were focused primarily on both direct, aquatic life, and indirect, human health, impacts. Three major groups of water quality parameters were considered: i) conventional and physical (11 parameters); ii) heavy metals (7 parameters); and iii) toxic substances (2 parameters). Water quality criteria for aquatic life (WQCA) and water quality criteria for human health (WQCH) are compared, and classified using colour codes (Tables 4-1 and 4-2).

Table 4-1: Classification of water quality based on aquatic life impacts.

No.	Station	Conventional (11 parameters)	Heavy metal (7 parameters)	Toxic (2 parameters)	WQCA
1	Houa Khong (LMH)	0	0	0	
2	Sob Rouak (TSR)	0	0	0	
3	Chiang Sean Pier 1 (TMC)	0	0	0	
4	Kok River Mouth (TKR)	0	0	1	
5	Chiang Khong (TCK)	0	0	0	
6	Luang Prabang (LPB)	0	0	0	
7	Vientiane (LVT)	0	0	0	
8	Nakhon Phanom (TNP)	0	0	0	
9	Xe Bang Fai (LFB)	0	Ns	0	
10	Kong Chiam (TMM)	0	0	0	
11	Pakse (LPS)	0	0	0	
12	Stung Treng (CMR)	0	0	0	
13	Siem Pang (CKM)	0	Ns	0	
14	Andoung Meas (CSS)	0	Ns	0	
15	Lumphat (CSP)	0	Ns	0	
16	Sekong River Mouth (CSR)	0	Ns	0	
17	Kratie (CKT)	0	0	0	
18	Chroy Changvar (CCV)	0	0	0	
19	Back Prea (CBP)	0	Ns	0	
20	Phnom Krom (CCK)	1	Ns	0	
21	Prek Kdam (CTU)	0	0	0	
22	Phnom Penh Port (CPP)	1	0	0	
23	Neak Loung (CNL)	0	0	0	
24	Koh Khel (CKL)	0	0	0	
25	Chau Doc (VCD)	0	0	0	
26	Tan Chau (VTC)	0	0	0	
27	Can Tho (VCT)	1	0	0	
28	My Thuan (VTR)	0	0	0	

Remarks
The number presented in the table is the number of parameters exceeded.
ns : Not sampled

BLUE: Very good water quality. All monitoring results of all three water quality groups (conventional parameter, heavy metal and toxic substance groups) complied with WQCA.

GREEN: Good water quality. Some monitoring results of the conventional and physical group, but all results of both heavy metal and toxic substance groups complied with WQCA.

YELLOW: Moderate water quality. All or some monitoring results of the conventional and physical group, but only some results of either heavy metal or toxic substance groups complied with WQCA.

RED: Fair water quality with indications of water deterioration. Only some monitoring of all three water quality groups (conventional parameter, heavy metal and toxic substance groups) complied with WQCA for all three major groups.

Table 4-2: Classification of water quality based on human health impacts.

No.	Station	Conventional (11 parameters)	Heavy metal (7 parameters)	Toxic (2 parameters)	WQCA
1	Houa Khong (LMH)	1	0	0	
2	Sob Rouak (TSR)	1	0	0	
3	Chiang Sean Pier 1 (TMC)	1	0	2	
4	Kok River Mouth (TKR)	1	0	1	
5	Chiang Khong (TCK)	1	0	2	
6	Luang Prabang (LPB)	1	0	0	
7	Vientiane (LVT)	1	0	1	
8	Nakhon Phanom (TNP)	1	0	0	
9	Xe Bang Fai (LFB)	1	ns	0	
10	Kong Chiam (TMM)	1	0	0	
11	Pakse (LPS)	2	0	1	
12	Stung Treng (CMR)	1	0	0	
13	Siem Pang (CKM)	1	ns	0	
14	Andoung Meas (CSS)	1	ns	0	
15	Lumphat (CSP)	1	ns	0	
16	Sekong River Mouth (CSR)	0	ns	0	
17	Kratie (CKT)	1	0	0	
18	Chroy Changvar (CCV)	1	0	0	
19	Back Prea (CBP)	2	ns	0	
20	Phnom Krom (CCK)	1	ns	0	
21	Prek Kdam (CTU)	2	0	0	
22	Phnom Penh Port (CPP)	1	0	1	
23	Neak Loung (CNL)	2	0	0	
24	Koh Khel (CKL)	2	0	0	
25	Chau Doc (VCD)	0	0	0	
26	Tan Chau (VTC)	1	0	0	
27	Can Tho (VCT)	2	0	1	
28	My Thuan (VTR)	0	0	0	

Remarks
The number presented in the table is the number of parameters exceeded.
ns : Not sampled

BLUE: Very good water quality. All monitoring results of all three water quality groups (conventional parameter, heavy metal and toxic substance groups) complied with WQCA.

GREEN: Good water quality. Some monitoring results of the conventional and physical group, but all results of both heavy metal and toxic substance groups complied with WQCA.

YELLOW: Moderate water quality. All or some monitoring results of the conventional and physical group, but only some results of either heavy metal or toxic substance groups complied with WQCA.

RED: Fair water quality with indications of water deterioration. Only some monitoring of all three water quality groups (conventional parameter, heavy metal and toxic substance groups) complied with WQCA for all three major groups.

4.2.2 SEDIMENT

Preliminary evaluation for this study program focuses on the heavy metal contamination, which relied on the Igeo technique. This technique is generally used for estimating anthropogenic input and assessing the pollution status of the area. The Igeo consists of seven classes (Tables 3-16 and 3-17). The colour code is not necessary in this case, since all results of the sampled stations showed only Pb concentrations ranging from I_{geo} class 1 (uncontaminated to moderate) to 3 (moderately to strongly contaminated).

4.2.3 BIOTA

From the existing data, both fish and mollusc tissues are only analysed for heavy metal contamination. Based on seven heavy metal residues in biota tissue, the colour classification system is shown in Table 4-3.

Table 4-3: Classification of biota quality based on European Commission 2006 standards.

No.	Station	Conventional (11 parameters)	Heavy metal (7 parameters)	Toxic (2 parameters)	WQCA
1	Houa Khong (LMH)	1	0	0	
2	Sob Rouak (TSR)	1	0	0	
3	Chiang Sean Pier 1 (TMC)	1	0	2	
4	Kok River Mouth (TKR)	1	0	1	
5	Chiang Khong (TCK)	1	0	2	
6	Luang Prabang (LPB)	1	0	0	
7	Vientiane (LVT)	1	0	1	
8	Nakhon Phanom (TNP)	1	0	0	
9	Xe Bang Fai (LFB)	1	ns	0	
10	Kong Chiam (TMM)	1	0	0	
11	Pakse (LPS)	2	0	1	
12	Stung Treng (CMR)	1	0	0	
13	Siem Pang (CKM)	1	ns	0	
14	Andoung Meas (CSS)	1	ns	0	
15	Lumphat (CSP)	1	ns	0	
16	Sekong River Mouth (CSR)	0	ns	0	
17	Kratie (CKT)	1	0	0	
18	Chroy Changvar (CCV)	1	0	0	
19	Back Prea (CBP)	2	ns	0	
20	Phnom Krom (CCK)	1	ns	0	
21	Prek Kdam (CTU)	2	0	0	
22	Phnom Penh Port (CPP)	1	0	1	
23	Neak Loung (CNL)	2	0	0	
24	Koh Khel (CKL)	2	0	0	
25	Chau Doc (VCD)	0	0	0	
26	Tan Chau (VTC)	1	0	0	
27	Can Tho (VCT)	2	0	1	
28	My Thuan (VTR)	0	0	0	

Remarks
The number presented in the table is the number of parameters exceeded.
ns : Not sampled

BLUE: Very good water quality. All monitoring results of all three water quality groups (conventional parameter, heavy metal and toxic substance groups) complied with WQCA.

GREEN: Good water quality. Some monitoring results of the conventional and physical group, but all results of both heavy metal and toxic substance groups complied with WQCA.

YELLOW**:** Moderate water quality. All or some monitoring results of the conventional and physical group, but only some results of either heavy metal or toxic substance groups complied with WQCA.

RED: Fair water quality with indications of water deterioration. Only some monitoring of all three water quality groups (conventional parameter, heavy metal and toxic substance groups) complied with WQCA for all three major groups.

5. CONCLUSIONS AND RECOMMENDATIONS

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This 2011 MMMAP study monitored 28 sampling stations: 25 existing stations regularly monitored by WQMN in member countries, and 3 additional stations monitored downstream of potential contaminant sources. Samples of water, sediment and biota samples were collected once in 2011, and analysed for basic water quality parameters, nutrients, heavy metals, pesticides and toxic substances.

Analysis results were compared with the available standard and previous MRC studies (WQMN data 2005–2010 and Diagnostic campaign 2003/2004). This evaluation indicates that overall environmental quality in the Mekong River mainstream and tributaries remains good, with a general trend of slightly deteriorating conditions being observed from upstream to downstream along the Mekong River. A slight increase in most parameters from the upper to lower part of the LMB is affected by an increase in human activities and areas of development, such as intensive agriculture and developing industrial zones. In addition, the rapid expanse in hydropower probably affects downstream locations. Although the sampling locations might imply causes, such as increasing human activities nearby or upstream, making any conclusions and/or identifying dominant pollution point sources in the location where levels are exceeded is not possible, as a result of the single sampling and the small number of sampling locations being evaluated.

Monitoring results between the mainstream and tributaries and among three sections of the Mekong River were compared. Generally, the water and sediment quality in both mainstream and tributaries were below the level of concern and of suitable condition for protection of aquatic life and human health. However, the water and sediment in tributaries tend to have higher levels of contaminants than the mainstream. This reflects significant development in each sub-basin. Most water quality parameters tend to increase from upstream (Mekong Section 1) to downstream (Mekong Section 3), with several exceptions of weather conditions, and/or specific conditions at certain sampling locations. Most elevated values can be explained by either current conditions during the sampling period or suspected point and non-point sources nearby. However, due to a lack of pollutant loading results on a catchment basis, indications of significant basin-wide trends of any parameters cannot be directly linked with contaminant loadings from agricultural, urban or industrial sources.

Sediment data should be interpreted cautiously due to variations of element background concentrations in the sediment. Further investigation and surveillance should be focused on the elevated heavy metal concentrations in sediment found in several locations from this study, particularly Pb values. Elevated values of Pb along the LMB in this study have prompted concerns about lack of historical sediment data.

For biota, the heavy metal and pesticide concentrations in fish and mollusc tissue living in the Mekong River were below the detection limit and much lower than threshold values for protection of human health and risk guidelines. This indicated that the pollutant contaminants in fish and mollusc inhabiting the lower Mekong River were far below the level of concern for human consumption. Although levels of heavy metal concentrations in fish indicate they are safe for human consumption, an elevated Hg level in fish raised a need for closer surveillance.

5.2 RECOMMENDATIONS

The 2011 MMMAP satisfactorily assessed current levels and distributions of contaminants within the LMB, updating a current baseline against the previous MRC baseline study for tracking changes over time in contaminant concentrations in different media (i.e. water, sediment, tissue). The study delivered an updated assessment of water, sediment and biota as a basis for identification of the ecological effects of contaminants as a part of future monitoring cycles. While the effects of individual point and non-point stresses are largely dissipated between widely spaced sampling stations, monitoring at Mekong mainstream and tributary stations should reveal any accumulation of persistent contaminants in sediments and their effects on benthic and fish communities.

Recognising that some impairment of water quality is occurring in the LMB, further recommendations for future MMMAP cycles are intended to: (i) better assess situations where water and sediment quality, and environmental receptors such as fish and aquatic organisms are being adversely affected by specific point and non-point contaminant loading; and in the longer term (ii) assess the effectiveness of pollution abatement measures such as planned urban wastewater treatment infrastructure or industry cleaner production. Refinements in the MMMAP scope and focus will be necessary to address these aspects.

The future MMMAP should specifically include: (i) inventory and monitoring of point and non-point urban, industrial and agricultural contaminant loadings in individual LMB sub-basins; (ii) monitoring of all major tributaries, considering both ambient water quality status, and tributaries as point sources of contaminants to the Mekong mainstream; and (iii) undertaking special studies to evaluate existing and potential threats in selected sub-basins and systems such as the Sesan, Sre Pok, Sekong (3Ss) which are subject to increasingly intensive development. Expansion of the MMMAP in this manner would enable the program to meet a wider variety of objectives, while ensuring that the overall body of data and information generated continues to support basin-wide assessments.

5.2.1 SAMPLING STATIONS

Contaminant characterisation undertaken as part of the 2011 program provides a solid basis for detailed inventory of pollution sources by sub-basin and future monitoring of environment quality in all or selected sub-basins. Additional stations should be monitored to provide necessary trend data, with new stations being situated to best assess probable changes in water quality from development activities resulting in point and non-point discharges. It is therefore recommended that the program continue to focus on sampling in depositional zones that are likely to have higher levels of contaminants.

While current WQMN and MMMAP stations are considered satisfactory to provide a baseline of water quality against which to measure change, many locations are generally either currently un-impacted or only marginally impacted by development activities, and therefore do not adequately assess impacts of contaminant discharges. Station locations should be optimised for future MMMAP cycles to better monitor conditions immediately downstream of large cities, major tributaries and other significant contaminant sources. Catchment basis is another approach to identify and locate pollution sources, and later contributing to pollution inventory. Sampling locations are also recommended to be located more in tributaries in relation to catchment inventory.

Additional stations should also be added to assess trans-boundary concerns, with intermediate stations providing a better understanding of changes in conditions from upstream to downstream and between countries, such as in various sub-basins, e.g. Nam Nuao, Nam Phuong, Huai Som Pak, and Huai Tomo (3Ss).

5.2.2 SAMPLING MATRICES

The 2011 MMMAP sample matrices should be included in the future MMMAP schedule. These matrices are namely water quality, bed sediment chemistry and bottom biota chemistry. For sediment, the results from MMMAP reveal that the pollutants are not accumulated in all bottom sediments, because the river-bed sediment in the Mekong River is very sandy, mostly containing > 90% sand particles. The sand particles are composed of quartz and are inert to any chemical reactions. The fine particles play very important roles in controlling pollutant distribution. Therefore, in areas where the sediment texture is fine, such as the Great Lake-Tonle Sap and Delta areas, the intensive sediment monitoring programmes should also be conducted. In addition, a geochemical approach should be taken into data interpretation, particularly heavy metals, not just the level of contaminants. Moreover, due to various elevated parameters found in the sediment study, reassessment of sediment quality is strongly recommended in the next monitoring program.

For biota chemistry, the results from MMMAP indicate that heavy metal and pesticides in fish and molluscs inhabiting the Mekong River were far below levels of concern for human consumption. To ensure safety for consumers in the region, additional groups of aquatic life, such as crustaceans and macrophytes, should be considered in the next monitoring programme. However, a closer surveillance to indicate possible bioaccumulation is recommended for future MMMAPs. A biota study in tributaries should be also considered, especially where mining activities and industries with chemical effluents are located.

5.2.3 SAMPLING SCHEDULES

The timing of sampling for future MMMAPs should remain unchanged, scheduled during the late dry season/wet season onset in an effort to characterise worst-case conditions. While acknowledging the desirability of monitoring during both wet and dry seasons, it is not recommended that MMMAP be undertaken twice-yearly due to the difficulty of sediment collection under high discharge conditions. Data provided by the regular WQMN monitoring is considered sufficient to characterise seasonal variability in water quality. However, if additional sampling locations in tributaries are included in future monitoring, the time of sampling should be reconsidered, depending on the difficulty of sediment collection under high discharge conditions.

5.2.4 SPECIAL GUIDELINES AND STUDY

Sediment guidelines may be established if there is an adequate amount of sediment and sedimentological and geochemical data for Mekong River sediment. An explicit designed protocol for intensive study to achieve this geochemical data set is imperative prior to establishing any sediment guidelines. It is highly recommended that more sediment information should be collected and an additional sediment survey should be conducted in both the mainstream and tributaries, especially in tributaries where hydropower projects and mining activities are located. However, setting a guideline value of sediment quality, as applied in water quality, is not recommended since geochemical and sedimentological properties of sediment should always be taken into account for all sediment data interpretation.

Consideration should also be given to including sediment toxicity testing in future monitoring programs to evaluate risks in the receiving environment by linking measurements of chemical exposure (e.g. sediment chemistry) to measurements of biological effects (e.g. sediment toxicity). A constraint faced in sediment toxicity testing in the program is that regional toxicity testing expertise is limited, possibly necessitating sending samples to qualified international bioassay laboratories. Alternatively, the programme could draw on prior bioassay testing experience of government and academic research laboratories, particularly in Thailand. Meanwhile, an intensive building capacity program for other laboratories in National Member Countries is strongly recommended.

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