MEKONG RIVER COMMISSION
For Sustainable Development

2020 LOWER MEKONG Water Quality MONITORING REPORT

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2020 LOWER MEKONG WATER QUALITY MONITORING REPORT

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
DHRW	Department of Hydrology and River Work
EC	Electrical conductivity
FC	Faecal coliform
GPHH	Guidelines for the Protection of Human Health
JEM	Joint Environmental Monitoring
HFWQ	High Frequency Water Quality Monitoring System
HYCOS	Hydrological Cycle Observing System
ISO	International Organization for Standardization
LMB	Lower Mekong Basin
MONRE	Ministry of Natural Resources and Environment
MOWRAM	Ministry of Water Resources and Meteorology
MPN	Most probable number
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NH4N	Ammonium
NMC	National Mekong Committee
NMCS	National Mekong Committee Secretariat
$NO_{3\text{-}2}$	Nitrate-nitrite
NRESRI	Natural Resources and Environment Statistic Research Institute
PDIES	Procedures for Data and Information Exchange and Sharing
PWQ	Procedures for Water Quality
QA/QC	Quality Assurance/Quality Control
RPM	Riverine Plastic Monitoring Programme
SM	Standard Methods for Water and Wastewater Examination
TGWQ	Technical Guidelines for the Implementation of the Procedures for Water Quality
TOTN	Total nitrogen

TOTP	Total phosphorus
TSS	Total suspended solids
UMB	Upper Mekong Basin
WQGA	MRC Water Quality Guidelines for the Protection of Aquatic Life
WQGH	MRC Water Quality Guidelines for the Protection of Human Health
WQI	Water Quality Index
WQI_{ag}	Water Quality Index for Agricultural Use
WQI_{al}	Water Quality Index for the Protection of Aquatic Life
WQI_{hh}	Water Quality Index for the Protection of Human Health
WQMN	Water Quality Monitoring Network

EXECUTIVE SUMMARY

Established in 1985, the Mekong River Commission (MRC) Water Quality Monitoring Network (WQMN) has provided continuous timeseries of water quality data in the Mekong River and its tributaries. The routine water quality monitoring under the WQMN is one of the MRC key environmental monitoring activities and is being carrying out to support the implementation of the Procedures for Water Quality (PWQ) and its Technical Guidelines. The actual monitoring of water quality is being implemented by the designated laboratories of the Member Countries (MCs) (Cambodia, Lao PDR, Thailand and Viet Nam) with technical supports from the MRC Secretariate (MRCS).

In 2020, the MRC and its Member Countries continued to monitoring water quality of the Mekong River and its tributaries at 48 locations across the Lower Mekong River Basin (LMB). At each station, 19 water quality parameters were monitored, of which 13 were considered as routine and were monitored on a monthly basis. The other six parameters (i.e. major anions and cations) were also monitored on a monthly basis but at the onset of the wet and Dry seasons.

In line with the objectives of the PWQ and the WQMN, this report provides an assessment of the status and spatiotemporal trends of water quality at all 48 stations. The assessment of the water quality status was carried out using both descriptive statistic analysis and water quality indices for various uses, including: (i) for the protection of human health; (ii) protection of aquatic life; and (iii) agricultural uses. The assessment of spatiotemporal trends was carried out using a combination of graphical illustration and statistical analyses to ascertain statistically significant levels of the observed spatial and temporal changes. Statistical analyses used in this report include the seasonal Mann-Kendall, independent t-test, and/or one-way Analysis of Variance (ANOVA) analyses. Pearson's correlation analysis was used to establish relationships among key water quality parameters. These relationships together with results of prior research within the LMB and other parts of the world were used to explain the status and trends of key water quality parameters detected in 2020.

Based on the assessment results of the 2020 water quality data obtained from the 48 stations of the MRC WQMN, the following key conclusions can be made on the status and spatiotemporal variation of water quality in the Mekong River and its tributaries:

- Water quality of the Mekong River and its major tributaries in 2020 varied spatially with water quality for the protection of human health rated from 'moderate' to 'excellent' water quality while water quality for the protection of aquatic life rated from 'poor' to 'high'. With regard to the protection of aquatic life, water quality of the Mekong and its tributaries remained generally either of 'good' to 'high' quality at stations located upstream of Cambodia/Viet Nam national boundary and generally 'poor' to 'moderate' quality for stations located in the Viet Nam's Mekong Delta owing to exceedance or non-compliance of key water quality parameters. Overall, exceedance and/or non-compliance with the MRC Water Quality Guidelines for the

Protection of Human Health (WQGH) and the MRC Water Quality Guidelines for the Protection of Aquatic Life (WQGA) were detected for four water quality indicators, including electrical conductivity (EC), dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and faecal coliform (FC). Of the remaining six parameters (pH, TSS, NO3-2, NH4, TOTN, and TOTP) used as proxies for water quality in this report, data of two parameters (pH and NO3-2) were well within their respective target values of WQGH and WQGA (at all 17 stations). However, it should be noted that when compared to the target values used for WQI_{hh}, WQIal, and WQI_{ag}, exceedance and/or non-compliance was detected for NO3-2 and TOTP in addition to COD, BOD, EC, and DO. Due to these exceedances, the water quality of the Mekong and its tributaries was rated as 'moderate' or 'poor' for the protection of aquatic life at five stations, all located in Viet Nam's Mekong Delta.

- Water quality at My Tho was influenced by elevated levels of EC in 2020. Specifically, EC levels at My Tho (VMT) exceeded the upper thresholds of WQGH (150 mg/L) at 33.3% sampling occasions with maximum concentration reaching 692.0 mS/m. However, it should be noted that these elevated levels only occurred during the Dry season. Regardless, water quality at VMT was determined to be severely restricted for both general and paddy irrigation. The elevated EC levels at VMT might have been influenced by increasing saltwater intrusion and will need to be further investigated as part of the planned regional study on the extent of salinity intrusion in the Mekong's Delta. Except for the restriction at VMT, water quality of the Mekong and its tributaries continued to pose no restriction for agricultural use.

- In addition to the EC levels at My Tho (VTM), impairment of water quality of the Mekong River was also detected with elevated concentrations of FC recorded in 2020 ranging from a non-detectable level to as high as 170,000 MPN/100 mL. Among the 17 mainstream stations, the most prevalent FC impairments were recorded at Neak Loung (CNL), where 100% of FC data exceeded the target value of WQGH (1,000 MPN/100 mL). Kampong Cham (CKC) (2,000 to 92,000 MPN/100 mL) and Chrouy Changvar (CCC) (1,700 to 68,000 MPN/100 mL) stations also recorded FC levels of more than 1,000 MPN/100 mL at all monitoring occasions. With the highest levels in the Mekong mainstream recorded during the Wet season months, instream FC levels may have been influenced by the current sanitation situations in the LMB, with open defecation rates remaining high among the rural populations of the MRC Member Countries.

- In the tributaries of the Mekong River, water quality impairments were detected at stations located immediately downstream of urban, agricultural and/or human activities influenced areas including Houay Mak Hiao (LHM), Phnom Krom (CPK), and Thong Binh (VTH), among others. At these stations, a combination of DO, COD, BOD, FC, and nutrients parmeters exceeded the target values of either WQGH, WQGA, WQI_{hh} and/or WQI_{al}.

- While water quality at all but one station was rated as either 'good' or 'excellent' for the protection of human health, elevated FC levels should be considered when utilizing the Mekong River and its tributaries as portable water.

- With DO continued to be one of the key water quality issues for many stations in 2020, water quality of the Mekong River and its tributaries at stations located in Viet Nam's Mekong Delta may not be suitable for the protection of human health and aquatic life. Of significant concern are DO levels recorded in the Mekong Delta, where DO concentrations as high as 94.4% were lower than the target value of WQGH (6 mg/L). Additionally, 22.2% of the DO concentrations measured at the three Viet Nam Delta's mainstream stations were lower than the target value of WQGA (5 mg/L), which could affect the aquatic fauna of the Delta.

- With Pearson's correlation analyses showing statistically significant negative relationship between DO levels and instream concentrations of EC, NO3-2, TOTP, COD, and BOD (p-value less than 0.01), it can be concluded that the reduction in DO levels was the direct result of the increased levels of EC, NO3-2, TOTP, COD, or BOD. The monitoring of these parameters, together with DO will need to be more intensive and may need to include a special investigation to explore potential point and non-point sources of these pollutants.

- In terms of potential transboundary water quality issue, the analyses of NO3-2, NH4N, TOTN and TOTP suggested potential transboundary water quality issue between Pakse (LPS) and Stung Treng (CST) with elevated NO3-2 and NH4N at CST compared to those at LPS. Instream NO3-2 is known as a primary food source for algae and could promote the proliferation of algae under appropriate climate and hydrological conditions.

- The differences in levels of both NO3-2 and NH4N between LPS (upstream station) and CST (downstream station) could indicate a potential transboundary water quality issue and must be further investigated. The investigation should be carried at CST to determine whether the sources of the elevated instream NO3-2 and NH4N are localized or transported from upstream with potential transboundary consequences. With the distance between the two stations being over 100 km, additional stations should be added between them to capture and ascertain any transboundary water quality issue. The discussion on the addition of stations between LPS and CST should be included in the core river network redesign or explored separately through the specific redesign of the WQMN.

The maintenance of 'acceptable/good' water quality of the Mekong River is key to achieving the objective of the PWQ. While the water quality of the Mekong River and its tributaries is still suitable for the protection of human health, aquatic life and agricultural uses at many locations across the LMB, levels of some water quality parameters have changed significantly compared to their historical records. Increase economic development, urbanization, and climate variability can further exacerbate these changes, as well as introducing emerging pollutants not previous seen in the river. Therefore, ensuring the relevance of the WQMN in responding to these emerging threats is crucial for the continued maintenance of 'good/acceptable' water quality of the Mekong River.

1. INTRODUCTION

1.1 BACKGROUND

Ranked as the 12th longest river, at about 4,880 km, and 8th in terms of mean annual discharge at its mouth at about 14,500 m^3/s (MRC, 2018), the Mekong River is one of the world's largest rivers. Originating in the Himalayas, the Mekong River flows southward through China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam. With a total catchment area of 810,000 km^2, the Mekong River Basin can be divided into the Upper Mekong Basin (UMB), which comprises an area in China where the Mekong is known as the Lancang River and makes up 23.2% of the total Mekong Basin (186,356 km^2), and the Lower Mekong Basin which comprises an area downstream of the Chinese border with Lao PDR.

The Lower Mekong River Basin (LMB) is functionally subdivided into four broad physiographic regions described by topography, drainage patterns and the geomorphology of river channels. These are the Northern Highlands, the Khorat Plateau, the Tonle Sap Basin and the Delta. With a total catchment area of about 623,644 km^2, the LMB covers a large part of Northeast Thailand, almost the entire countries of Lao PDR and Cambodia, and the southern tip of Viet Nam (MRC, 2018).

According to the 2018 State of the Basin Report (MRC, 2018), the Lower Mekong River is home to about 70 million people, of whom about 85% live in rural areas where many practises subsistence farming, with supplemental fish catch for livelihoods and food security. The Mekong River is also one of the most bio-diverse rivers in the world with estimated 1,148 fish species (MRC, 2019). The river's annual flood pulse continues to support a rich natural fishery and an extensive and unique wetland environment. This makes the rich ecology of the Basin extraordinarily important in terms of its contribution to livelihoods and sustainable development. As such, water quality monitoring is an integral part of detecting changes in the Mekong riverine environment and for maintaining good/acceptable water quality to promote the sustainable development of the LMB.

1.2 WATER QUALITY MONITORING NETWORK AND THE PROCEDURES FOR WATER QUALITY

1.2.1 Water Quality Monitoring Network

Recognising that sustainable development of water resources of the LMB will not be possible without effective management of water quality, the MRC Member Countries (MCs) agreed to establish the Water Quality Monitoring Network (WQMN) in 1985 with the specific objectives of monitoring the status and detecting changes in the Mekong River water quality and ensuring preventive and remedial actions are taken if any changes are detected. Between 1985 and 1992, the WQMN comprised of stations in Lao PDR, Thailand, and Viet Nam. Cambodia later joined the WQMN in 1993 when it started to routinely monitor water quality within its national boundary.

Since its inception, the WQMN has provided valuable information on the condition of the river water quality which is integral to the 70 million people who live in the basin and continue to depend on the resources and values provided by the Mekong River ecosystems. Historically, over 120 water quality stations were monitored as part of the WQMN across the LMB (Table 1.1). The peak sampling year was recorded in 2005 when 90 stations were monitored. In 2006, the MRC led by the Environment Programme, conducted a full assessment of water quality monitoring activities in the Mekong River under the WQMN. One of the outcomes of the assessment was the need to reduce the cost of the monitoring while at the same time increase its relevance and suitability in detecting changes associated with the basin rapid economic development and population growth. An agreement was reached for the Network to include only primary stations while the secondary stations would be monitored by individual Member Countries. Primary stations are those that are located in the mainstream and key tributaries of the Mekong River. Since 2006, 48 stations have been classified as "primary stations" and were designed to detect changes and capture pressures and threats to Mekong water quality. A number of these stations were also strategically selected to detect transboundary water quality problems. In 2020, these stations continued to be monitored by the MCs as part of the WQMN. Of these 48 stations, 17 were located along the Mekong mainstream while the remaining stations (31) were located in the tributaries of the Mekong River (Section 2.1).

Table 1.1. Water quality monitoring stations under the 2020 MRC WQMN

Countries	STATID	Station name	Names of water body	Monitoring period		Status*
				Started	Ended	
Cambodia	H014501	Stung Treng	Mekong	10/24/04		A
Cambodia	H014901	Kratie	Mekong	7/11/95		A
Cambodia	H019801	Chrouy Changvar	Mekong	8/12/93		A
Cambodia	H019802	Kampong Cham	Mekong	8/25/93		A
Cambodia	H019806	Neak Loung	Mekong	8/24/93		A
Cambodia	H019807	Kaorm Samnor	Mekong	10/16/04		A
Cambodia	H020101	Phnom Penh Port	Tonle Sap River	7/15/95		A
Cambodia	H020102	Prek Kdam	Tonle Sap River	8/25/93		A
Cambodia	H020103	Kampong Chnang	Tonle Sap River	7/18/95		A
Cambodia	H020106	Kampong Loung	Tonle Sap Lake	7/16/95		A
Cambodia	H020107	Back Prea	Sangkeo (Tonle Sap)	10/21/04		A
Cambodia	H020108	Phnom Krom	Tonle Sap Lake	10/20/04		A
Cambodia	H033401	Takhmao	Bassac River	7/14/95		A
Cambodia	H033402	Koh Khel	Bassac River	8/24/93		A
Cambodia	H033403	Koh Thom	Bassac River	10/16/04		A
Cambodia	H430102	Siem Pang	Se Kong River	10/24/04		A
Cambodia	H440102	Phum Pi	Se San River	11/23/04		A
Cambodia	H440103	Angdoung Meas	Se San River	10/22/04		A
Cambodia	H450101	Lumphat	Sre Pok River	10/22/04		A
Cambodia	H610101	Kampong Thom	Stung Sen River	10/19/04		A
Cambodia	H620101	Kompong Thmar	Stung Chinit River	10/19/04	12/23/08	N
Cambodia	H640110	Kampong Toul	Prek Thnot	7/15/95	12/14/03	N
Lao PDR	H010500	Houa Khong	Mekong	8/17/04		A

Countries	STATID	Station name	Names of water body	Monitoring period		Status*
				Started	Ended	
Lao PDR	H011200	Luang Prabang	Mekong	7/12/04		N
Lao PDR	H011201	Luang Prabang	Mekong	5/19/85	6/17/04	N
Lao PDR	H011901	Vientiane	Mekong	5/15/85		A
Lao PDR	H013401	Savannakhet	Mekong	1/18/01		A
Lao PDR	H013900	Pakse	Mekong	7/15/04		A
Lao PDR	H013901	Pakse	Mekong	7/12/85	6/17/04	N
Lao PDR	H100101	Ban Hatkham	Nam Ou River	6/13/85		A
Lao PDR	H230102	Tha Ngon	Nam Ngum River	5/15/85	6/15/04	N
Lao PDR	H230103	Ban Hai	Nam Ngum River	7/12/04		A
Lao PDR	H230199	Nam Ngum 1 Dam	Nam Ngum River	5/10/85	12/16/08	N
Lao PDR	H230206	Thalath	Nam Lik River	3/14/88	12/16/08	N
Lao PDR	H231801	Nam Souang	Nam Souang River	1/24/01	12/16/08	N
Lao PDR	H231901	Nam Houm	Nam Houm River	2/13/95	12/16/08	N
Lao PDR	H320101	Se Bangfai Bridge	Se Bangfai River	6/18/85	12/16/15	A
Lao PDR	H350101	Ban Kengdone	Se Banghieng River	5/24/85		A
Lao PDR	H390104	Souvannakhili	Sedone River	1/15/89	12/16/08	N
Lao PDR	H390105	Sedone Bridge	Sedone River	7/16/04		A
Lao PDR	H390199	Sedone Dam	Sedone River	5/20/85	12/16/03	N
Lao PDR	H910103	Houa Khoua	That Luong Swamp	8/19/86	12/16/08	N
Lao PDR	H910106	Ban Sok	That Luong Swamp	2/13/95	12/16/08	N
Lao PDR	H910107	Donedeng	That Luong Swamp	1/24/01	12/16/08	N
Lao PDR	H910108	Houay Mak Hiao	Houay Mak Hiao	7/19/04		A
Thailand	H010501	Chiang Sean	Mekong	5/15/85		A
Thailand	H013101	Nakhon Phanom	Mekong	5/15/85		A
Thailand	H013801	Khong Chiam	Mekong	5/15/85		A
Thailand	H050104	Chiang Rai	Mae Kok River	5/15/85		A
Thailand	H290102	Ban Tha Kok Daeng	Song Khram River	5/15/85	5/13/04	N
Thailand	H290103	Ban Chai Buri	Song Khram River	6/16/04		A
Thailand	H310102	Na Kae	Kam River	5/15/85		A
Thailand	H370104	Yasothon	Chi River	5/15/85	12/14/05	N
Thailand	H370115	Ban Kok	Chi River	5/15/85	5/18/04	N
Thailand	H370122	Ban Chot	Chi River	5/15/85	5/17/04	N
Thailand	H370299	Nam Pong Dam	Pong River	5/15/85	5/18/04	N
Thailand	H371203	Ban Tad Ton	Huai Pa Thao River	1/15/90	5/17/04	N
Thailand	H371499	Lam Pao Dam	Pao River	5/15/85	5/18/04	N
Thailand	H380103	Ubon	Mun River	5/15/85		A
Thailand	H380127	Kaeng Saphu Tai	Mun River	5/15/85	5/17/04	N
Thailand	H380128	Mun (Khong Chiam)	Mun River	6/15/04		A
Thailand	H380133	Ban Som	Mun River	1/15/90	5/17/04	N
Thailand	H380134	Rasi Salai	Mun River	5/15/85	12/14/05	N
Thailand	H380903	Ban Ku Phra Ko Na	Lam Seio Yai River	5/15/85	5/17/04	N
Thailand	H381699	Lam Dom Noi	Mun River	5/15/85	12/14/05	N
Viet Nam	H019803	Tan Chau	Mekong River	4/14/86		A
Viet Nam	H019804	My Thuan	Mekong River	12/14/86		A
Viet Nam	H019805	My Tho	Mekong River	4/14/86		A
Viet Nam	H029812	Dai Ngai	Bassac River	10/15/04	12/15/09	N

Countries	STATID	Station name	Names of water body	Monitoring period		Status*
				Started	Ended	
Viet Nam	H039801	Chau Doc	Bassac River	8/14/86		A
Viet Nam	H039803	Can Tho	Bassac River	6/14/86		A
Viet Nam	H440201	Kon Tum	Se San River	3/15/92	3/15/95	N
Viet Nam	H440202	Pleicu	Se San River	10/15/04		A
Viet Nam	H440601	Trung Nghia	Se San River	3/15/92	3/15/95	N
Viet Nam	H450502	Giang Son	Sre Pok River	1/15/93	2/15/95	N
Viet Nam	H450701	Duc Xuyen	Sre Pok River	1/15/92	2/15/95	N
Viet Nam	H451303	Ban Don	Sre Pok River	7/15/04		A
Viet Nam	H988101	Hong Ngu	Hong Ngu Canal	3/13/86	12/15/03	N
Viet Nam	H988102	Tan Thanh	Hong Ngu Canal	3/13/86	6/15/09	N
Viet Nam	H988103	Cai Mon	Hong Ngu Canal	3/13/86	12/15/03	N
Viet Nam	H988104	An Long	Dong Tien Canal	3/13/86	12/15/03	N
Viet Nam	H988105	Tram Chim	Dong Tien Canal	12/16/86	2/15/10	N
Viet Nam	H988106	Hung Thanh	Phuoc Xuyen Canal	3/13/86	3/15/10	N
Viet Nam	H988107	Kien Binh	Duong Van Duong Canal	3/13/86	4/15/10	N
Viet Nam	H988108	Tuyen Nhon	Lagrang Canal	3/13/86	12/15/03	N
Viet Nam	H988109	Phong My	Thap Muoi Canal	3/13/86	12/15/03	N
Viet Nam	H988110	My An	Canal No 28	3/13/86	7/15/10	N
Viet Nam	H988111	My Phuoc Tay	Nguyen Tan Thanh Canal	3/13/86	8/15/10	N
Viet Nam	H988112	Rach Chanh	Rach Chanh Canal	3/13/86	9/15/10	N
Viet Nam	H988113	Long Dinh	Nguyen Tan Thanh Canal	3/13/86	10/15/10	N
Viet Nam	H988114	Tu Thuong	Tu Thuong Canal	7/15/04		A
Viet Nam	H988115	Thong Binh	Thong Binh Canal	7/15/04		A
Viet Nam	H988201	My Xuyen	Bai Xao Canal	7/25/88	6/15/04	N
Viet Nam	H988202	My Thanh	My Thanh Canal	7/25/88	6/15/04	N
Viet Nam	H988203	Nhu Gia	Nhu Gia Canal	7/25/88	6/15/04	N
Viet Nam	H988204	Cau Sap	Ngan Dua Bac Lieu Canal	7/25/88	6/15/09	N
Viet Nam	H988205	Ho Phong	Canh Den Ho Phong Canal	7/25/88	6/15/09	N
Viet Nam	H988206	Ca Mau	Quan Lo Phung Hiep Canal	7/27/88	6/15/09	N
Viet Nam	H988207	Chu Chi	Cho Hoi Canal	7/27/88	6/15/09	N
Viet Nam	H988208	Thoi Binh	Chac Bang Canal	7/27/88	6/15/09	N
Viet Nam	H988209	Vinh Thuan	Chac Bang Canal	7/27/88	6/15/09	N
Viet Nam	H988210	Ngan Dua	Ngan Dua Canal	7/27/88	6/15/09	N
Viet Nam	H988211	Ninh Quoi	Quan Lo Phung Hiep Canal	7/27/88	6/15/09	N
Viet Nam	H988212	Nga Nam	Quan Lo Phung Hiep Canal	7/27/88	6/15/04	N
Viet Nam	H988213	Phung Hiep	Quan Lo Phung Hiep Canal	7/27/88	6/15/04	N
Viet Nam	H988214	Phuoc Sinh	Quan Lo Phung Hiep Canal	3/15/90	6/15/09	N
Viet Nam	H988301	Nui Sap	Rach Gia Long Xuyen Canal	8/15/91	6/15/04	N
Viet Nam	H988302	Ba The	Ba The Canal	8/15/91	6/15/04	N
Viet Nam	H988303	Tri Ton	Tri Ton Canal	8/15/91	6/15/04	N
Viet Nam	H988304	Nha Bang	Tra Su Canal	8/15/91	6/15/04	N
Viet Nam	H988305	Cau So 13	Tri Ton Canal	1/15/04	6/15/09	N

Countries	STATID	Station name	Names of water body	Monitoring period		Status*
				Started	Ended	
Viet Nam	H988306	Cau So 5	Ba The Canal	1/15/04	6/15/09	N
Viet Nam	H988307	Vong Dong	Rach Gia Long Xuyen Canal	1/15/04	6/15/09	N
Viet Nam	H988308	Vong The	Ba The Canal	1/15/04	6/15/09	N
Viet Nam	H988309	Cau Tri Ton	Tri Ton Canal	1/15/04	6/15/09	N
Viet Nam	H988310	Lo Gach	Tam Ngan Canal	8/15/91	6/15/09	N
Viet Nam	H988311	Vinh Dieu	T3 Canal	8/15/91	6/15/09	N
Viet Nam	H988312	Tam Ngan	Tam Ngan Canal	8/15/91	6/15/09	N
Viet Nam	H988313	Tri Dien	Tri Ton Canal	8/15/91	6/15/09	N
Viet Nam	H988314	Soc Xoai	Rach Gia Ha Tien Canal	8/15/91	6/15/09	N
Viet Nam	H988315	My Lam	Rach Gia Ha Tien Canal	8/15/91	6/15/09	N
Viet Nam	H988316	Tinh Bien	Vinh Te Canal	8/15/91		A

Note: * "A" denotes an active station while "N' denotes a non-active or discontinued monitoring station.

In 2020, 19 water quality parameters were monitored by the WQMN (Section 2.3), although during its peak years, between 1995 and 2004, up to 23 water quality parameters were monitored. These parameters comprised physical, chemical and bacteriological parameters, and have been determined as critical for assessing the effects of development on the quality of the Mekong River water for the protection of aquatic life and human health (Sections **Error! Reference source not found.**, **Error! Reference source not found.**, and 2.4.1.2.2), as well as to support the maintenance of agricultural productivity in the LMB (Section 2.4.1.2.3).

The WQMN is one of the MRC's core river basin monitoring activities that will be decentralized to the MCs for full implementation. Following decentralisation, MCs through their designated water quality laboratories will be required to fully finance and undertake the monitoring, sampling, and analysis of the Mekong and its tributaries water quality. At national level, each Member Country has designated a national water quality laboratory to undertake the monitoring, sampling, and analysis of Mekong water quality (Table 1.2).

Table 1.2. Designated National WQMN, 2020

National Water Quality Laboratory	Ministries	Member Countries
The Department of Hydrology and River Works (DHRW)	Ministry of Water Resources and Meteorology	Cambodia
The Natural Resources and Environment Research Institute (NRERI)	Ministry of Natural Resources and Environment	Lao PDR
The Water Quality Analysis Division, Department of Water Resources	Ministry of Natural Resources and Environment	Thailand
The Southern Institute for Water Resources Planning	Ministry of Natural Resources and Environment	Viet Nam

The designated laboratories are responsible for undertaking routine monitoring and measurement of 19 water quality parameters (Table 2.3). They are also responsible for analysing, assessing, sharing, and reporting water quality data on an annual basis. Their specific duties are to:

- conduct routine monthly water quality monitoring of the Mekong River and its tributaries as defined in their Terms of Reference;
- participate in the annual MRC quality assurance/quality control (QA/QC) auditing which includes proficiency testing (PT) and internal auditing to ensure consistency and integrity of the recorded data;
- manage water quality data in accordance with the agreed format and submit the data to the MRCS for validation and sharing through the MRC data portal; and
- produce and publish annual water quality data assessment report, outlining the results of water quality monitoring, analysis, and assessment.

At the regional level, the MRCS is responsible for providing technical support for the monitoring of water quality and to ensure the integrity and compatibility of data recorded at the national level. The MRCS also acts as a central hub for maintaining regional water quality data and provides a platform for data exchange in accordance with the MRC Procedures for Data and Information Exchange and Sharing (PDIES) and its Technical Guidelines. In addition, the MRCS conducts regional data quality assurance, quality control and analysis, and prepare regional annual report on water quality monitoring of the LMB.

1.2.2 Procedures for Water Quality

Routine water quality monitoring under the WQMN has become an integral part of sustainable water resources development in the LMB with the establishment of the 1995 Mekong Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin which led to the adoption of the Procedures for Water Quality (PWQ) in 2011. With its objective being "*to establish a cooperative framework for the maintenance of acceptable/good water quality to promote the sustainable development of the LMB*", PWQ provides systematic guidelines for the MCs to individually and/or jointly manage water quality and respond to any water quality incident that would constitute an emergency within their respective national boundaries and in the Mekong River.

To support the implementation of the PWQ, MCs have jointly developed and adopted the Technical Guidelines for the Implementation of the Procedures for Water Quality (TGWQ) consisting of two main parts dealing with the management of water quality (Part I) and framework for responding to water quality emergency incident (Part II). Since its adoption, the implementation of Part I of the TGWQ has been through the implementation of the WQMN. With the first part of the TGWQ provides systematic guidelines for the management of water quality for the protection of human health (Chapter 1) and the protection of aquatic life (Chapter 2), MCs have integrated these guidelines into the routine activities of the WQMN, including the adoption of methods for field sampling, laboratory analysis, and data assessment that ensure the comparability of the monitoring data.

Chapters 1 and 2 aim to provide decision support tools "for the management by the Member Countries to maintain good/acceptable water quality of the Mekong mainstream". Water quality criteria (indicators and target values) of the key parameters were collaboratively adopted by the Member Countries to support them in maintaining a good/acceptable water quality. In Chapter 1, water quality criteria are grouped into two types (direct impact parameters and indirect impact parameters) depending on their characteristics and their potential effects on human health (Table 1.3 and Table 1.4).

Table 1.3. Water quality criteria for the protection of human health (Direct Impact Parameters)

No	Parameters	Symbol	Unit	Value	Analytical method[(1)]
1	Total arsenic	Total As	mg/l	0.01	3550-As/SM
2	Cadmium	Cd	mg/l	0.005[(2)]	3110-Cd/SM
3	Chromium hexavalent	Cr	mg/l	0.05	3550-Cr/SM
4	Cyanide	CN	mg/l	0.01	4500-CN/SM
5	Lead	Pb	mg/l	0.05	3110-Pb/SM
6	Total mercury	Total Hg	mg/l	0.002	3112-Hg/SM
7	Oil and grease	• ***Should not occur in such a way that:*** • it can be observed as an oil film, sheen, or discolouration; • it has an odour; or • it can be seen as oily deposits on the riverbank and/or at the river bottom.			Observation
8	Phenol	C_6H_5OH	mg/l	0.005	5530-Phenol/SM
9	Total organochlorine pesticide		mg/l	0.05	6630-organochlorinePesticides/SM
10	Faecal coliforms		MPN/100 ml	1,000[(3)]	9230-Ecoli Group/SM

[(1)] If the laboratories rely on their own methods and/or non-standard methods, they have to comply with the requirements of method validation of ISO/IEC 17025-2005
[(2)] When the water hardness is less than 100 mg/l as $CaCO_3$
[(3)] An interim target value requiring further review by the TBWQ. The TBWQ with support from the Mekong River Commission Secretariat will continue to study this issue in order to reconsider the interim target value

Table 1.4. Water quality criteria for the protection of human health (Indirect Impact Parameters)

No	Parameters	Symbol	Unit	Value	Analytical method[(1)]
1	Ammonia as N	NH_3 as N	mg/l	0.5[(2)]	4500-NH_3/SM
2	Biological oxygen demand	BOD_5	mg/l	4	5210-BOD_5/SM
3	Chemical oxygen demand	COD_{Mn}	mg/l	5	$KMnO_4$ method
4	Conductivity	EC	mS/m	70–150	2510-Ec/SM
5	Dissolved oxygen	DO	mg/l	≥ 6[(3)]	4500-O/SM
6	Total nitrite and nitrate as N	(NO_2 + NO_3) as N	mg/l	5	4500-NO_3/SM
8	pH	pH		6-9	4500-H^+/SM
9	Temperature	T	°C	Natural	2550-Temp/SM
10	Total Coliform		MPN/100ml	5,000	9221-Coliform group/SM

[(1)]If the laboratories use their in-house methods and/or non-standard methods, they have to comply with the requirements of method validation of ISO/IEC 17025-2005.
[(2)] An interim target value requiring further review by the TBWQ. The TBWQ with support from the Mekong River Commission Secretariat will continue to study this issue in order to reconsider the interim target value
[(3)] An interim target value requiring further review by the TBWQ. The TBWQ with support from the Mekong River Commission Secretariat will continue to study this issue in order to reconsider the interim target value.

Water quality criteria agreed for Chapter 2 are also grouped into two types of Direct Impact Parameters and Environmental Stressor Parameters as changes in these parameters can directly affect or increase stress to the physiology of aquatic organisms (Table 1.5).

Table 1.5. Water quality criteria for the protection of aquatic life (direct impact parameters (No. 1 to 10) and Environmental Stressor Parameters (No. 11 to 18))

No	Parameters	Symbol	Unit	Value	Analytical method[1]
	Name				
1	Arsenic	Total As	mg/l	0.01	3550-As/SM
2	Cadmium	Cd	mg/l	0.005[2]	3110-Cd/SM
3	Chromium hexavalent	Cr (VI)	mg/l	0.05[3]	3550-Cr/SM
4	Copper	Cu	Mg/l	0.1	
5	Cyanide	CN	mg/l	0.005	4500-CN/SM
6	Lead	Pb	mg/l	0.05[4]	3110-Pb/SM
7	Total mercury	Total Hg	mg/l	0.001[5]	3112-Hg/SM
8	Oil and grease[6]	***Should not occur in such a way that:*** • it can be observed as an oil film, sheen, or discolouration; • it has an odour, or • it can be seen as oily deposits on the riverbank and/or at the river bottom.			Observation
9	Phenol	C_6H_5OH	mg/l	0.005	5530-Phenol/SM
10	Total organochlorine pesticide		mg/l	0.05	6630-organochlorinePesticides/SM
11	Ammonia	NH_3 as N	mg/l	0.2[8]	4500-NH_3/SM
12	Biological oxygen demand	BOD_5	mg/l	3[7]	5210-BOD_5/SM
13	Dissolved oxygen	DO	mg/l	> 5	4500-O/SM
14	pH	pH		6-9	4500-H^+/SM
15	Temperature		°C	Natural	2550-Temp/SM
16	Nitrite[9]	NO_2 as N			
17	Nitrate	NO_3 as N	mg/l	5	4500-NO_2-C/SM
18	Phosphate[9]	PO_4 as P			

(1) If the laboratories use their in-house methods and/or non-standard methods, they have to comply with the requirements of method validation of ISO/IEC 17025-2005
(2) *When the water hardness is less than 100 mg/l as $CaCO_3$*
(3), (4),(5),(6) and (7) An interim target value requiring further review by the TBWQ. The TBWQ with support from the Mekong River Commission Secretariat will continue to study this issue in order to reconsider the interim target value.
(8) An interim target value requiring further review by the TBWQ. The TBWQ with support from the MRC Secretariat will continue to study this issue in order to reconsider the interim target value. Thailand proposes 0.5 mg/l; Vietnam proposes 0.1 mg/l.
(9) Target values will be proposed in the future when the national standard target values for Lao PDR and Thailand are available.

1.3 OBJECTIVES

The routine water quality monitoring under the WQMN has become one of the key environmental monitoring activities implemented under the MRC Environmental Management Division. Its importance is captured in the MRC Basin Development Strategy for 2021 2030, where two major outputs are expected on an annual basis annual water quality data and an annual water quality and data assessment report. This report has been prepared in response to these required outputs. It provides the consolidated results from the water quality monitoring activities of the MCs, focusing on the compliance of water quality data with target values established in the TGWQ for the protection of human health and aquatic life, as discussed in Section 1.2.2 (Table 1.3, Table 1.4 and Table 1.5). As such, the main objectives of this report are to:

- provide the status of water quality in the Mekong River in 2020 by assessing water quality monitoring data monitored by the WQMN laboratories in 2020 against the target values established by the TGWQ (Section 1.2.2);
- perform an exploratory analyse of any spatial changes observed in the Mekong River water quality in 2020;
- identify annual mean temporal changes observed for key water quality indicators at all 48 stations of the WQMN;
- perform an exploratory analysis and discuss any potential transboundary water quality issues observed in 2020;
- assess the suitability of the Mekong water quality for the protection of human health, the protection of aquatic life, and/or to support the productivity of the agricultural activities in the LMB; and
- provide recommendations for future monitoring and continuous improvement of the water quality monitoring activities in the LMB.

2. MATERIALS AND METHODS

2.1 MONITORING LOCATIONS AND FREQUENCY

Forty-eight stations were monitored by the WQMN in 2020. A breakdown of the number of stations in each Member Country is presented in Table 2.1. As can be seen in the table, of the 48 stations monitored in 2020, 11 stations were located in Lao PDR, 8 in Thailand, 19 in Cambodia and 10 in Viet Nam. Spatially, the routine monitoring of water quality was carried out across the LMB at 17 mainstream stations and 31 tributaries stations. Of significant importance, water quality of the 3S and Tonle Sap River systems was monitored at five stations (three in Cambodia and two in Viet Nam) and six stations, respectively. For the Bassac River, water quality was monitored at five stations with three of these stations (Takhmao, Koh Khel and Koh Thom) located in Cambodia side of the river while the other two stations (Chau Doc and Can Tho) located in Viet Nam. For the Mun River System, two stations have been established to provide historical records of water quality of the river, while water quality of the Mae Kok, Nam Ou, Nam Ngum, Se Bangfai, Se Banghieng, and Se Done Rivers was also monitored in 2020 and historically at one station each (Table 2.2 and Figure 2.1).

This report contains the analyses of water quality conditions including status and trends at all 48 mainstream and tributary stations. In this report, the names of these stations have been abbreviated as indicated in Table 2.2, and their spatial locations are illustrated in Figure 2.1.

For consistency, the Member Countries agreed to carry out a monthly sampling and monitoring of water quality between the 13^{th} and 18^{th} day of each month.

Table 2.1. A summary of 2020 water quality monitoring stations

Countries	No. of Stations	No. on the Mekong River	No. on tributaries	Monitoring Frequency
Lao PDR	11	5	6	Monthly
Thailand	8	3	5	Monthly
Cambodia	19	6	13	Monthly
Viet Nam	10	3	7	Monthly
Total	48	17	26	Monthly

Table 2.2. The 48 water quality stations included in the 2020 Lower Mekong Water Quality Monitoring Report

Station[1] abbr.	WQMN station ID	Station name	River name	Country	Latitude	Longitude
LHK	H010500	Houa Khong	Mekong River	Lao PDR	21.5471	101.1598
TCS	H010501	Chiang Sean	Mekong River	Thailand	20.2674	100.0908
LBK	H100101	Ban Hatkham	Nam Ou River	Lao PDR	20.0850	102.2522
LLP	H011200	Luang Prabang	Mekong River	Lao PDR	19.9388	101.3038
TCR	H050104	Chiang Rai	Mae Kok River	Thailand	19.9208	99.84610
LBH	H230103	Ban Hai	Nam Ngum River	Lao PDR	18.1792	103.0565
LHM	H910108	Houay Mak Hiao	Houay Mak Hiao	Lao PDR	17.9999	102.9082
LVT	H011901	Vientiane	Mekong River	Lao PDR	17.9692	102.5506
TBC	H290103	Ban Chai Buri	Song Khram River	Thailand	17.6438	104.4616
TNP	H013101	Nakhon Phanom	Mekong River	Thailand	17.4250	104.7744
LSB	H320101	Se Bangfai	Se Bangfai River	Lao PDR	17.0800	104.9847
TNK	H310102	Na Kae	Nam Kam River	Thailand	16.9572	104.5041
LSV	H013401	Savannakhet	Mekong River	Lao PDR	16.5583	104.7522
LBD	H350101	Ban Kengdone	Se Banghieng River	Lao PDR	16.1836	105.3167
TMK	H380128	Mun (Kong Chiam)	Nam Mun River	Thailand	15.3036	105.4888
TKC	H013801	Khong Chaim	Mekong River	Thailand	15.3255	105.4937
TUB	H380104	Ubon	Nam Mun River	Thailand	15.2430	104.9547
LPS	H013900	Pakse	Mekong River	Lao PDR	15.1136	105.7854
LSD	H390105	Sedone bridge	Se Done River	Lao PDR	15.0716	105.4842
CSP	H430102	Siempang	Sekong River	Cambodia	14.1192	106.3933
CAM	H440103	Angdoung Meas	Se San River	Cambodia	14.0469	107.1069
CPH	H440102	Phum Pi	Se San River	Cambodia	13.7914	107.4486
CLP	H450101	Lumphat	Srepork River	Cambodia	13.5494	106.5283
CST	H014501	Stung Treng	Mekong River	Cambodia	13.5450	106.0164
CBP	H020107	Backprea	Sang Keo River	Cambodia	13.3086	103.3992
CPK	H020108	Phnom Krom	Tonle Sap Lake	Cambodia	13.2938	103.8172
CKL	H020106	Kampong Luong	Tonle Sap Lake	Cambodia	12.6008	104.2211
CKR	H014901	Kratie	Mekong River	Cambodia	12.4700	106.0200
CKN	H020103	Kampong Chnang	Tonle Sap River	Cambodia	12.2694	104.6822
CKC	H019802	Kampong Cham	Mekong River	Cambodia	11.9942	105.4689
CKD	H020102	Prek Kdam	Tonle Sap River	Cambodia	11.8153	104.8072
CPP	H020101	Phnom Penh Port	Tonle Sap River	Cambodia	11.5867	104.9232
CCC	H019801	Chrouy Changvar	Mekong River	Cambodia	11.5861	104.9407
CTK	H033401	Takhmao	Bassac River	Cambodia	11.4785	104.9530
CKK	H033402	Koh Khel	Bassac River	Cambodia	11.2676	105.0292
CNL	H019806	Neak Loung	Mekong River	Cambodia	11.2579	105.2793
CKT	H033403	Koh Thom	Bassac River	Cambodia	11.1054	105.0678

[1] Here, the names of the 48 stations have been abbreviated.

Station[1] abbr.	WQMN station ID	Station name	River name	Country	Latitude	Longitude
CKS	H019807	Kaorm Samnor	Mekong River	Cambodia	11.0679	105.2086
VTC	H019803	Tan Chau	Mekong River	Viet Nam	10.9036	105.5206
VCD	H039801	Chau Doc	Bassac River	Viet Nam	10.8253	105.3367
VTB	H988316	Tinh Bien	Vinh Te Canal	Viet Nam	10.8253	105.3367
VMH	H019804	My Thuan	Mekong River	Viet Nam	10.8044	105.2425
VCT	H039803	Can Tho	Bassac River	Viet Nam	10.7064	105.1272
VMT	H019805	My Tho	Mekong River	Viet Nam	10.6039	104.9436
VBD	H451303	Ban Don	Sre Pok River	Viet Nam	10.5206	105.8458
VPC	H440202	Pleicu	Se San River	Viet Nam	10.4361	105.0553
VTH	H988115	Thong Binh	Thong Binh Canal	Viet Nam	10.3431	106.3506
VTT	H988114	Tu Thuong	Tu Thuong Canal	Viet Nam	10.2725	105.9100

(blue)	Denotes mainstream stations
(white)	Denotes other tributary stations including those located in the Bassac, 3S, and Tonle Sap Basins

Note: The stations are arranged in descending order of latitide.

Figure 2.1. Spatial distribution of the 48 primary water quality stations monitored by the WQMN, 2020

2.2 SAMPLING TECHNIQUES

In an effort to standardize the sampling techniques, in 2020, the MRC worked with the designated WQMN Laboratories of the Member Countries to identify appropriate sampling techniques for collecting water samples. Through consultations, it was agreed that in 2020, water quality sampling, preservation, transportation, and storage would be carried out in accordance with methods provided in the TGWQ (Section 1.2.2), which were prepared in accordance with the 23rd edition of the Standard Methods for the Examination of Water and Wastewater (Baird, 2017) or in accordance with national standards complying with the requirements of method validation of ISO/IEC 17025-2005.

Specifically, the designated laboratories are required to:

- collect water samples using the simple surface grab technique at the middle of the stream where free flowing water is observable;
- collect water samples at about 30 cm to 50 cm under the surface of the stream;
- if in-situ measurement is not possible, immediately preserve samples collected with proper preservative agents (i.e. sulphuric acid for nutrients measurement) and store in a cooler to prevent further breakdown of chemicals and biological contents; and
- analyse all water samples within the recommended holding time.

All designated laboratories of the MRC WQMN are required to adhere to the MRC QA/QC procedures outlined in the TGWQ, which were developed in accordance with ISO/IEC 17025-2005 and personnel safety procedures when collecting water samples and measuring water quality parameters.

2.3 LABORATORY ANALYTICAL METHODS

Since its inception in 1985, the WQMN has provided data on water quality in the Mekong River and its selected tributaries by measuring a number of different water quality parameters. At its peak, the network provided a measurement of 23 water quality parameters. However, in 2020, 19 water quality parameters were measured by the MRC WQMN (Table 2.3). Twelve of the 19 parameters measured in 2020 are considered routine water quality parameters that must be measured for each monitoring month; the other seven major anions and major cations must be analysed monthly for each sample taken between May and October.

In addition to providing a list of parameters measured by the MRC WQMN, Table 2.3 provides a list of recommended analytical methods used for measuring water quality parameters, as mentioned in Section 2.2.

Table 2.3. Water quality parameters and their corresponding analytical methods

Analytical parameter	MRC WQMN Recommended analytical methods[2]	Frequencies
Temperature	2550-Temp/SM	Monthly
pH	4500-H^+/SM	Monthly
Electrical conductivity (EC)	2510-EC/SM	Monthly
Alkalinity/acidity	2320-A/SM	Monthly (May, October)
Dissolved oxygen (DO)	4500-O/SM	Monthly
Chemical oxygen demand (COD)	Permanganate oxidation	Monthly
Total phosphorous (TOTP)	4500-P/SM	Monthly
Total nitrogen (TOTN)	4500-N/SM	Monthly
Ammonium (NH_4N)	4500-NH_4/SM	Monthly
Total nitrite and nitrate ($NO_{2\text{-}3}$)	4500-$NO_{2\text{-}3}$/SM	Monthly
Faecal coliform (FC)	9221-Faecal Coliform group/SM	Monthly
Total suspended solids (TSS)	2540-D-TSS-SM	Monthly
Calcium (Ca)	3500-Ca-B/SM	Monthly (May, October)
Magnesium (Mg)	3500-Mg-B/SM	Monthly (May, October)
Sodium (Na)	3500-Na-B/SM	Monthly (May, October)
Potassium (K)	3500-K-B/SM	Monthly (May, October)
Sulphate (SO_4)	4500- SO_4 –E/SM	Monthly (May, October)
Chloride (Cl)	4500-Cl/SM	Monthly (May, October)
Biochemical oxygen demand (BOD_5)	5210-BOD_5/SM	Monthly

2.4 WATER QUALITY DATA ASSESSMENT

The analyses of water quality data in 2020 require the collation and validation of water quality collected at the national level by the Member Countries. The successful validation of these national databases enabled the agglomeration of regional water quality databases, which facilitated basin-wide analysis of water quality status and trends. Figure 2.2 illustrates the approach used for water quality data analysis to support this regional water quality data assessment report. The figure highlights four key types of data analyses encompassing the assessment water quality status in 2020, the spatial of assessment of changes in 2020, the temporal assessment of changes, and the exploratory analysis of potential transboundary water quality issues. The methodology and approach used for these analyses are discussed in detail in Sections 2.4.1 to 2.4.4, and consisted of the following:

[2] Member Countries can use their national methods for the analyses of water quality parameters provided that the methods have been validated to produce scientifically comparable results with the methods recommended by the MRC WQMN.

- an evaluation of the status of the Mekong River water quality as recorded in 2020 (Section 2.4.1), in comparison to MRC water quality thresholds as listed in Chapter 1 "Guidelines for the Protection of Human Health" (Table 1.3 and Table 1.4) and Chapter 2 "Guidelines for the Protection of Aquatic Life" (Table 1.5);
- exploratory analyses of spatial variation of water quality along the Mekong River mainstream using a variety of proven statistical techniques, as discussed in Section 2.4.2 of this report;
- an assessment of temporal variation of key water quality indicators at all 48 stations monitored in 2020 using a variety proven statistical techniques, as discussed in Section 2.4.3 of this report; and
- exploratory analyses and discussions on the potential transboundary water quality issues at the stations that have been strategically established to detect the conditions of water quality entering and leaving national boundaries of the Member Countries (2.4.4).

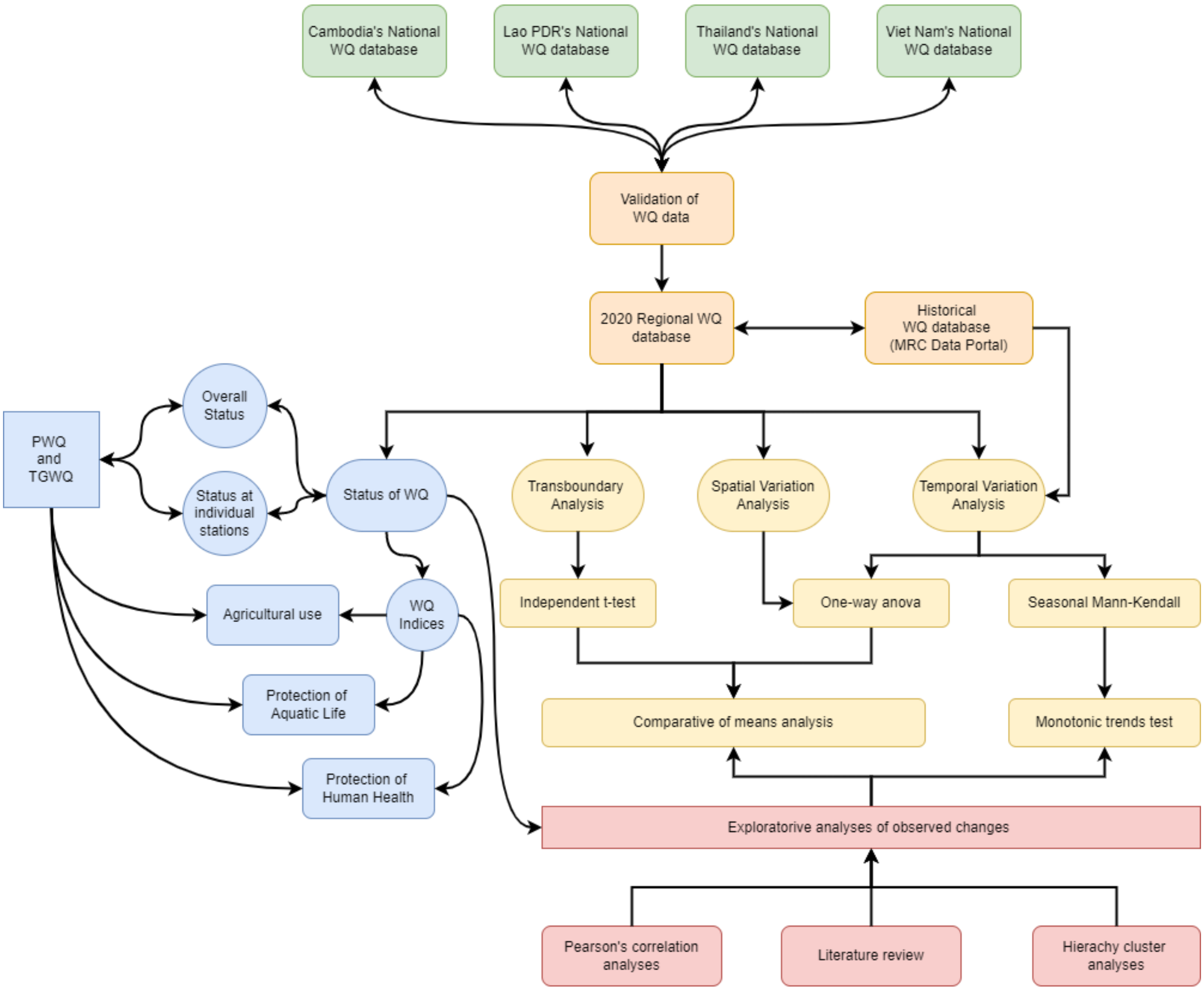

Figure 2.2. Conceptual illustration of the approaches use for the analyses of 2020 water quality data to support the identification of water quality status and spatiotemporal variation

2.4.1 Assessment of Water Quality Status

2.4.1.1 Descriptive Statistical Analysis

The overall status of the Mekong water quality in 2020 was examined by applying descriptive statistics, such annual maximum, mean, and minimum to summarize data series of key water quality parameters collected in 2020 along the Mekong River. Descriptive statistics are commonly used to analyse and compare various aspects of water quality data (Fisher and Marshall, 2009; He et al., 2009; Johnson et al., 2009; Ai et al., 2015; Gu et al., 2019), because they provide quick snapshots of data series that are generally large and not event-distributed (Fisher and Marshall, 2009; Lee, 2020). These values were compared to the water quality thresholds of the MRC Water Quality Guidelines for the Protection of Human Health (Chapter 1 of the TGWQ) and for the Protection of Aquatic Life (Chapter 2 of the TGWQ) to identify any exceeded values that need special attention (Section 1.2.2 and Table 1.3, Table 1.4, and Table 1.5). In the absence of the water quality thresholds of Chapters 1 and 2 of the TGWQ, the descriptive concentrations of water quality indicators were compared against thresholds used for the assessment of the MRC Water Quality Indices (Section 2.4.1.2 and Table 2.4, Table 2.6, and Table 2.8). Any exceedance and/or non-compliance observed in any key water quality parameters was further characterized at the individual station level (Table 2.2) through an additional descriptive statistical analysis assessment. These descriptive statistical concentrations were compared against the MRC water quality thresholds listed in Chapters 1 and 2 of the TGWQ, as well as those established specifically for the MRC Water Quality Indices. In addition, the proportions of data points that exceeded or violated water quality thresholds were also determined to quantify the extent or scale of water quality issues.

As illustrated in Figure 2.2, the assessment results of water quality status are then used as key information to support the exploratory analyses pertaining to the assessment of spatiotemporal changes and transboundary water quality issues (Sections 2.4.2, 2.4.3, and 2.4.4).

2.4.1.2 Water Quality Indices

The assessments of the status of water quality of the Mekong for specific use and conservation were carried out through the utilization of previously adopted MRC Water Quality Indices. In 2013, the MRC Member Countries adopted three indices, taking into account the requirements of the PWQ and its TGWQ (Section 1.2.2). These indices include:

- Water Quality Index for the Protection of Aquatic Life (WQI_{al})
- Water Quality Index for the Protection of Human Health (WQI_{hh})
- Water Quality Index for Agricultural Use, which is divided into two categories (WQ_{ag}): (i) general irrigation and (ii) paddy rice.

2.4.1.2.1 Water Quality Index for the Protection of Aquatic Life

The Water Quality Index for the Protection of Aquatic Life is calculated using Equation 2.1. It was developed as an open-ended index, which would allow more parameters to be added once data become available (Campbell, 2014). In this annual water quality report, only six parameters are included. These parameters, together with their target values, are listed in Table 2.4. The classification system for the Water Quality Index for the Protection of Aquatic Life is summarized in Table 2.5.

$$WQI_{al} = \frac{\sum_{i=1}^{n} p_i}{M} \qquad \text{Equation 2.1}$$

Where:

- "p_i" is the point scored on sample day i. If each parameter listed in
- Table 2.4 meets its respective target value in
- Table 2.4 one point is scored; otherwise the score is zero
- "n" is the number of samples from the station in the year
- "M" is the maximum possible score for the measured parameters in the year.

Table 2.4. Parameters used for calculating the rating score of the Water Quality Index for the Protection of Aquatic Life, together with their target values

Parameters	Target Values
pH	6 – 9
EC (mS/m)	150
NH_3 (mg/L)	0.1
DO (mg/L)	≥5
$NO_{2\text{-}3}$ (mg/L)	0.5
TOTP (mg/L)	0.13

Table 2.5. Rating systems for the Water Quality Index for the Protection of Aquatic Life

Rating Score	Class
9.5 ≤ WQI ≤10	A: High Quality
8 ≤ WQI < 9.5	B: Good Quality
6.5 ≤ WQI < 8	C: Moderate Quality
4.5 ≤ WQI < 6.5	D: Poor Quality
WQI < 4.5	E: Very Poor Quality

2.4.1.2.2 Water Quality Index for the Protection of Human Health

With the finalization of Chapter 1 (Guidelines for the Protection of Human Health (HH)) of the Technical Guidelines for the Implementation of the Procedures for Water Quality, the MRC Member Countries have agreed to include HH in the analysis of water quality of the Mekong River. To assist in communicating water quality information concerning the protection of human health, water quality indices and classification systems were developed, focusing on human health acceptability and human health risk.

The Human Health Acceptability Index utilizes parameters of indirect impact, as identified by the HH while the human health risk index utilizes direct impact parameters. The rating score for both indices can be calculated using Equation 2.2, which is based on the Canadian Water

Quality Index (CCME, 2001; Khan et al., 2005). It should be noted that since the monitoring of direct impact parameters has not commenced, Member Countries have agreed to adopt only the human health acceptability index. The list of the approved parameters to be included in the calculation of the rating score for the human health acceptability index, together with their target values are listed in Table 2.6. The classification system for the Water Quality Index for the Protection of Human Health – Human Acceptability Index is summarized in Table 2.7.

$$WQI_{hh} = 100 - \left(\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right) \quad \text{Equation 2.2}$$

Where, F_1 is the percentage of parameters which exceed the guidelines and can be calculated by **Equation 2.3**.

$$F_1 = \left(\frac{\#\ of\ failed\ parameters}{Total\ \#\ of\ parameters}\right) \quad \text{Equation 2.3}$$

F_2 is the percentage of individual tests for each parameter that exceeded the guideline and can be calculated by **Equation 2.4**.

$$F_2 = \left(\frac{\#\ of\ failed\ tests}{Total\ \#\ of\ tests}\right) \quad \text{Equation 2.4}$$

F_3 is the extent to which the failed test exceeds the target value and can be calculated using **Equation 2.5**.

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right) \quad \text{Equation 2.5}$$

Where nse is the sum of excursions and can be calculated using **Equation 2.6**.

$$nse = \left(\frac{\sum excursion}{Total\ \#\ of\ tests}\right) \quad \text{Equation 2.6}$$

The excursion is calculated by **Equation 2.7**.

$$excursion = \left(\frac{failed\ test\ value}{guideline\ value}\right) - 1 \quad \text{Equation 2.7}$$

Table 2.6. Parameters used for calculating the rating score of the Water Quality Index for the Protection of Human Health together with their target values

Parameters	Target Values
pH	6 – 9
EC (mS/m)	150
NH_3 (mg/L)	0.5
DO (mg/L)	≥4
NO_{2-3} (mg/L)	5
COD (mg/L)	5
BOD[3] (mg/L)	4

Table 2.7. Rating systems for the Water Quality Index for the Protection of Human Health

Rating Score	Class	Description
95 ≤ WQI ≤100	A: Excellent Quality	All measurements are within objectives virtually all of the time
80 ≤ WQI < 95	B: Good Quality	Conditions rarely depart from desirable levels
65 ≤ WQI < 80	C: Moderate Quality	Conditions sometimes depart from desirable levels
45 ≤ WQI < 65	D: Poor Quality	Conditions often depart from desirable levels
WQI < 45	E: Very Poor Quality	Conditions usually depart from desirable levels

2.4.1.2.3 Water Quality Index for Agricultural Use

Another index adopted by the MRC Member Countries as a means for communicating water quality monitoring information to the public is the Water Quality Index for Agricultural Use, which focuses on water quality for general irrigation and paddy rice. The indices for general irrigation and paddy rice are calculated based on the MRC water quality guidelines for salinity (EC). The EC guidelines, together with the degree of consequence, for the indices for general irrigation and paddy rice are outlined in Table 2.8.

Table 2.8. Electrical conductivity guidelines and degrees of consequence for Water Quality Index for Agricultural Use – general irrigation and paddy rice

Irrigation Raw Water	Unit	Degree of Consequence*		
		None (A)	Some (B)	Severe (C)
Electrical Conductivity				
General Irrigation	mS/m	<70	70-300	>300
Paddy Rice	mS/m	<200	200-480	>480

Note: * None = 100% yield; some = 50–90% yield; severe = <50% yield

[3] Due to the required holding time for BOD, MCs have agreed to only monitor BOD at stations where samples can be analyzed within the required holding time of less than 48 hours. Therefore, BOD was only included for the stations where data is available.

2.4.2 Assessment of Spatial Variations

In this report, two distinct groups of spatial variation assessments were carried out for stations located in the Mekong River mainstream and for those located in tributaries of the Mekong River including the Bassac River. As shown in Table 2.2, water quality monitoring under the WQMN was carried out at 17 mainstream stations, five Bassac stations, and 26 other tributary stations. The main aim of the spatial variation was to examine the differences in measurement levels of key water quality parameters along the Mekong River Mainstream and its key tributaries, including the Bassac Rivers. Variations of key water quality parameters monitored at these stations were assessed utilizing both graphical illustration methods and statistical analyses.

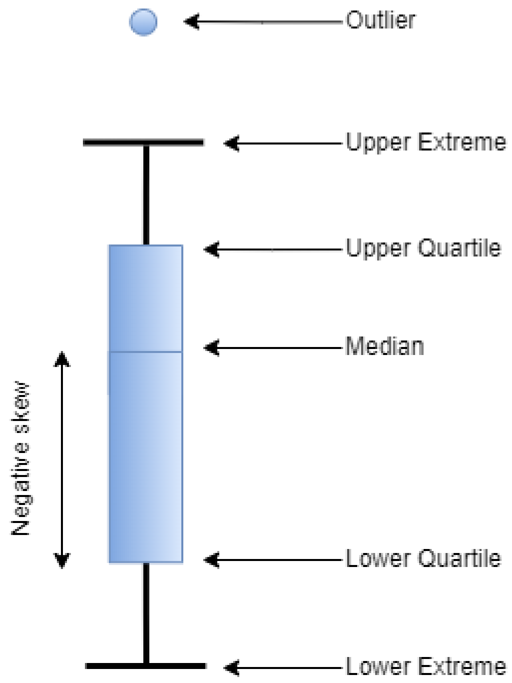

Figure 2.3. Information visualized by box-and-whisker plot

Graphically, the box and whisker plot (Thompson, 1992; DuToit et al., 2012) was used to visualize the distribution of 2020 water quality data for key parameters. While water quality data can be graphically illustrated in multiple ways bythe box and whisker plot, the method is non-parametric statistical and has often been used to support the analysis of non-normal distribute data, such as environmental monitoring data including water quality data, which is highly susceptible to the influences of seasonality and surrounding natural and anthropogenic factors (Larsen, 1985; Thirumalai et al., 2017; Ly et al., 2020). Using the box and whisker plot, key elements of the dataset can be easily extracted including the information on the minimum, maximum, median, and first and third quartile of the dataset (Larsen, 1985). As such, the box and whisker plot is an ideal graphical visualization for comparing data distribution of different dataset (e.g. water quality data from different stations or time step) due to their immediate apparent of the centre, spread and overall range (Statistics Canada, 2021). Additionally, the box and whisker plot can provide valuable information on the distribution of the dataset through its visualization of the skewness of data, which can be used to support the identification of appropriate statistical analysis techniques and/or data pre-treatments (Boddy and Gordon, 2009). In this regional report, the box and whisker visualizations of water quality data were carried out using the 28th Version of IBM SPSS Statistical Software (IBM Corp., 2021).

The use of the box and whisker plot for the spatial variation assessment of the 2020 water quality data along the 17 mainstream stations was supported by the analyses of mean differences between the mainstream stations using one-way analysis of variance (one-way ANOVA) (Heiberger and Neuwirth, 2009; Kim, 2017; Ross and Willson, 2017). This is because while the box and whisker plot may visually indicate spatial water quality variations among the stations monitored in 2020, these variations may be affected by outliers and data abnormality. To ascertain that these spatial variations are statistically significant, one-way ANOVA analyses were carried out for each water quality parameters across the basin. In environmental and data sciences, one-way ANOVA is commonly used to determine whether the observed differences in means of three or more independent datasets (e.g. dataset from three or more water quality stations) are statistically significant (Ross and Willson, 2017). Specifically, for the spatial assessment of water quality in this regional report, the one-way ANOVA was used to compare the means of key water quality parameters of the 17 mainstream stations. In doing so, one-way ANOVA was used to test the validity of a null hypothesis as detailed in Equation 2.8.

$$H_0: \mu_1 = \mu_2 = \mu_3 = \cdots = \mu_n \qquad \text{Equation 2.8}$$

Where:

μ_1 represents the mean concentration of station 1 (e.g., Houa Khong Station (LHK)),
μ_2 represents the mean concentration of station 2 (e.g., Chiang Sean Station (TCS)),
μ_3 represents the mean concentration of station 3 (e.g., Luang Prabang Station (LLP)), and so on, and
μ_n represents the mean concentration of station n, or for the purpose of this regional report – station 17 (e.g. My Tho Station).

Should the one-way ANOVA test yield a statistical significant result (Equation 2.8), an alternative hypothesis (H_A) would be accepted, indicating that the mean concentration of the water quality parameter of at least two stations is statistically significant from one another (Heiberger and Neuwirth, 2009; Kim, 2017). In this regional report, the use of the one-way ANOVA was accompanied by the normality test, with the transformation of non-normal distributed data (Azhar et al., 2015; Monica and Choi, 2016).

Pearson's correlation analyses (Franzese and Iuliano, 2019) were performed to establish relationships between these parameters and to help explain the variation observed. In statistic and data sciences, Pearson's correction coefficient (also known as Pearson's r) is used to measure the linear correlation between two or more datasets (Benesty et al., 2009;

Connolly et al., 2015; Ly et al., 2020). In doing so, Pearson's r estimates the ratio between the covariance of two or more datasets (e.g. [pH]:[NO3-2]; [pH:[COD]; or [pH]:[TOTP], etc.)[4] and the product of their standard deviations (Benesty et al., 2009). When applying to datasets, Pearson's correlation coefficient can be estimated by Equation 2.9 (ibid.), as follows:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad \text{Equation 2.9}$$

Where:

r_{xy} is the Pearson's correlation coefficient of the two datasets (x and y) being tested;
x_i and y_i are individual concentrations of the two water quality parameters monitored at time i; and
$\bar{x}$ and $\bar{y}$ are the mean concentration of dataset x and y, respectively.

In addition to the Pearson's correlation, this regional report also utilizes previously published literature and/or scientific research articles in exploring the potential natural and/or anthropogenic influences of the observed spatial water quality variations in the Mekong River mainstream (Figure 2.2).

2.4.3 Assessment of Temporal Variations

Unlike the past regional water quality data assessment reports, the 2020 Regional Water Quality Data Assessment Report assesses temporal variations at the station level, with all temporal changes in key water quality parameters were examined at all 48 stations. At many of these stations, historical data dated back to 1985. Therefore, all available records of water quality data were used for temporal assessment, covering the 1985–2020 period for many stations. Similar to the assessment of spatial variations (Section 2.4.2), a combination of graphical visualizations and statistical analyses was applied to the historical record of key water quality parameter, allowing for the detection and assertion of any temporal changes.

Visually, a cluster bar chart was used to illustrate changes in mean annual concentrations of key water quality parameters. Similar to the assessment and analyses of spatial variation, changes observed in mean annual concentrations were confirmed statistically by one-way ANOVA (Section 2.4.2).

In addition to assessing changes in mean annual concentration of key water quality parameters, their monotonic trends were assessed by the seasonal Mann-Kendall test (Hirsch, Slack and Smith, 1982; Ly et al., 2020). Known as a non-parametric statistical method, the seasonal Mann-Kendall test has been well utilized in the field of environment monitoring and assessment due to its flexibility and suitability for non-normal distributed datasets that susceptible to seasonal influences (Ly et al., 2020; Von Sperling, Verbla and Oliveira, 2020). Proposed by Hirsch et al. (1982) as a seasonal modification to the Mann-Kendall test (Al-Mashagbah and Al-Farajat, 2013), the seasonal Mann-Kendall test the following null and alternative hypotheses:

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[4] As an example, [pH]:[NO_{3-2}] denotes a ratio of pH dataset to that of NO_{3-2}.

H_0 = No monotonic trend over the temporal monitoring period
H_A = For one or more seasons, there is an upward or downward monotonic trend over the temporal monitoring period.

The seasonal Mann-Kendall test then used to compute the Z_{SK} statistic value of the datasets as per Equations 2.10 to 2.12 (Hirsch et al., 1982).

$$Z_{sk} = \frac{S^{'} - 1}{\sqrt{VAR(S^{'})}} \quad if\ S^{'} > 0$$ Equation 2.10

$$Z_{sk} = 0 \quad if\ S^{'} = 0$$ Equation 2.11

$$Z_{sk} = \frac{S^{'} + 1}{\sqrt{VAR(S^{'})}} \quad if\ S^{'} < 0$$ Equation 2.12

Where:
S' = the seasonal statistic of the Mann-Kendall test and is the sum of the signs of difference between all combinations of observations

VAR(S') = its variance.

Hirsch et al. (1982) provide a detailed, step-by-step approach to calculating these statistics. In this regional report, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_A) is accepted if $|Z_{SK}| \geq Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is the $100(1-\alpha/2)^{th}$ percentile of the standard normal distribution. In this regional report, the seasonal Mann-Kendall test was carried out using an open source statistical software RStudio (RStudio, 2022).

To explain the observed statistically significant changes in both mean annual concentration (one-way ANOVA) and monotonic trend (seasonal Mann-Kendall test), similar exploratory analyses approaches used for the spatial variation analyses (Section 2.4.2) were applied. Specifically, these include the use of Pearson's correlation coefficients supplemented by previously published literature and/or research journals.

2.4.4 Exploration of Potential Transboundary Water Quality issues

The MRC (2008), in its Technical Paper No. 19, identified the following five main transboundary areas along the Mekong River for assessing transboundary water quality in the Mekong and Bassac Rivers;

1. **People's Republic of China/Lao PDR** — A water quality monitoring station was established in Houa Khong (LHK) in 2004 to monitor the boundary between the Upper and Lower Mekong Basin.

2. **Lao PDR/Myanmar** — There is no water quality station in this part of the river since it is remote and sparsely populated.

3. **Thailand/Lao PDR** — There is a number of monitoring stations along this stretch of the Mekong River, including those located in the vicinity of urban areas such as Vientiane (LVT), Nakhon Phanom (TNP) and Savannakhet (LSV). However, none of the stations can be referred to as transboundary stations since they receive run-off from both countries, and water is normally sampled in the middle of the river.

4. **Lao PDR/Cambodia** — While not located directly at the border of the two countries, Pakse (LPS) and Stung Treng (CST) monitoring stations have, in the past, been considered transboundary stations. Data from these stations have been used to assess transboundary effects on water quality.

5. **Cambodia/Viet Nam** — Both the Mekong and the Bassac Rivers have stations that can be used to capture transboundary effects on water quality. On the Mekong side, Kaorm Samnor station (CKS) in Cambodia and Tan Chau (VTC) station in Viet Nam are located not too far from the Cambodian/Vietnamese border. Similarly, Koh Thom station (CKT) in Cambodia and Chau Doc station (VCD) in Viet Nam, which are located on the Bassac River, can be considered transboundary stations due to their proximity to the Cambodian/Vietnamese border.

6. **Viet Nam/Cambodia** – In 2020, the MRC WQMN monitored the water quality of the 3S (Se Kong, Se San and Srepork Rivers) River System at six locations.: Siemphang (CSP) on the Sekong River, Pleicu (VPC), Phum Pi (CPH), and Angdoung Meas (CAM) on the Se San River, and Ban Don (VBD), and Lumphat (CLP) on the Srepork River. Among these six stations, Pleicu (VPC), and Phum Pi (CPH) can be considered transboundary stations due to their proximity to the national boundary and to one another. Therefore, this report included these two stations when exploring potential transboundary water quality issues.

In exploring potential transboundary water quality issues among the identified transboundary stations, this 2020 water quality report utilizes both graphical visualization and statistical analysis to exploratorily ascertain the different in levels of key water quality parameters monitored at these stations. Specifically, the water quality datasets from these stations were visualized by the box and whisker plot (Section 2.4.2 and Figure 2.3).

Statistically, the two-sample t-test (Wilcox, 1990; Fu and Wang, 2012; Gerald, 2018; von Sperling, Verbyla and Oliveira, 2020) was used to determine whether there was a statistically significant difference between the mean concentrations of key water quality parameters of the two transboundary stations. In statistic and data science, the t-test allows to compare the average values of two datasets by determining their statistical significance through the computation of their t-statistic, t-distribution and the degree of freedom. Wilcox (1990) provides a detailed discussion and step-by-step approach on the computation of the statistics, but in this 2020 regional report, the two-sample t-test was used to test whether a null hypothesis (H_0) in this mean concentration of water quality parameters at two stations are equal (Equation 2.13) can be rejected. Should the t-test return statistically significant results at 0.05 level, alternative hypothesis (H_A) would be accepted (Equation 2.14).

$$H_0\colon \mu_1 = \mu_2 \qquad \text{Equation 2.13}$$
$$H_A = \mu_1 \neq \mu_2 \qquad \text{Equation 2.14}$$

Where:
μ_1 and μ_2 denote the average concentrations of a water quality parameter at station 1 and station 2, respectively. In this report, the sample t-test analysis was carried out using the 28th Version of IBM SPSS Statistical Software (IBM Corp., 2021).

Similar to the approaches used for the spatiotemporal exploratory assessment, Pearson's correlation coefficients and previously published literature and/or research articles were then used to support the discussion of the observed differences of water quality at these transboundary stations.

2.5 QUALITY ASSURANCE / QUALITY CONTROL

Recognizing the need to improve the quality, precision, and accuracy of the water quality data, all designated laboratories of the MRC WQMN were requested to participate in the implementation of a quality assurance and quality control (QA/QC) test for water sampling, preservation, transportation, and analysis from 2004. The goal of the implementation of the QA/QC procedures is to ensure that the designated laboratories carry out their routine water quality monitoring activities in accordance with the TGWQ and international standard ISO/IEC 17025-2005. To date, of the four designated laboratories of the MRC WQMN, the laboratories in Lao PDR and Viet Nam have received ISO/IEC 17025-2005 certification. The certifications were given by the Bureau of Accreditation, Directorate for Standards and Quality of Viet Nam.

Other designated laboratories, although not ISO/IEC 17025-2005 certified, have rigorously implemented the MRC WQMN QA/QC in Sampling and Laboratory Work or national QA/QC procedures that meet the requirements of the ISO/IEC 17025-2005. The MRC QA/QC procedure calls for the designated laboratories to:

- Be well prepared for each sampling event, have a sampling plan with clear sampling objectives and ensure that sampling teams are equipped with appropriate sampling and safety equipment and preservative chemical reagents;
- Apply quality control during sampling, which consists of taking duplicate samples and field blanks for certain parameters;
- Analyse all water samples within recommended holding times;
- Conduct routine maintenance and calibration of all measurement equipment;
- Conduct data analysis using control chart and reliability score testing using the ion balance test; and
- Archive raw data and any important information relating to the results of the analysis in order to allow to trace all data and reconfirm the results of the analysis.

3. RESULTS

3.1 STATUS OF THE MEKONG WATER QUALITY IN 2020

In 2020, the water quality of the Mekong River and its tributaries was monitored at 48 stations (Section 2.1 and Table 2.2), which yielded a total of 3,721 data points for the 17 stations located in the Mekong mainstream; 923 data points for the five Bassac River stations; and 4,670 data points for the 26 tributary stations. The 2020 water quality statuses were assessed separately for mainstream. Bassac and tributaries stations against the objectives of the MRC PWQ (Section 1.2.2) to ascertain whether the water was still of 'good/acceptable' quality. Specifically, 2020 water quality data of key parameters were compared against their respective target values adopted by the MRC Member Countries for Chapter 1 (WQGH) and Chapter 2 (WQGA) of the TGWQ.

Using a commonly applied descriptive statistical analysis (Section 2.4.1.1), the maximum, mean and minimum values of key water quality parameters were determined for stations located in the Mekong River (Table 3.1 and Annex A), Bassac River (Table 3.2 and Annex B), and selected tributaries (Table 3.2 and Annex C). As with other types of environmental monitoring timeseries data, water quality timeseries data of the MRC WQMN is lengthy and influenced by numerous factors including seasonality. Summarizing the data using descriptive statistics allows for a quick assessment of whether the water of the river is still of 'good/acceptable' quality compared to the established target values (Fu and Wang, 2012; von Sperling et al., 2020). The status of water quality in the Mekong mainstream, Bassac River, and tributaries of the Mekong River in 2020 are discussed separately in Sections 3.1.1 to 3.1.2.

While historical records of water quality in the Mekong and Bassac River are included in Table 3.1 and Table 3.2, the spatial and temporal variations are discussed in detailed in Section 3.2.

3.1.1 Mekong Water Quality in 2020

Results of descriptive statistical analyses of water quality data from 17 Mekong mainstream stations (Section 2.1 and Table 2.2) reveal that the water of the Mekong River in 2020 was overall of moderately good quality with exceedance of WQGH and WQGA detected for five water quality indicators (Table 3.1), including EC, DO, COD, BOD, and FC. Of the remaining six parameters (pH, TSS, NO3-2, NH4, TOTN, and TOTP) used as proxies for water quality in this report, data of two parameters (pH and NO3-2) with established target values were well within their respective target values of WQGH and WQGA at all 17 stations (Table 3.1).

Of the five water quality parameters with data values exceeding the target values of WQGH and WQGA, EC values were 100% beyond the recommended target range of 70–150 mS/m of the WQGH. Of these values in 2020, 2% were higher than 150 mS/m, with the highest EC value of 692.0 mS/m recorded at My Tho (VMT) station in March 2020 (Annex A). Since My Tho is the final monitoring station in the Mekong River mainstream before the river discharges into the East Sea, elevated EC levels were recorded due to saltwater intrusion. In 2020, 33.3% of the EC data recorded at VMT were greater than 150 mS/m.

In contrast, 98% of EC data recorded in 2020 was less than 70 mS/m, which is the lower threshold of the EC target values of WQGH (Chapter 1). The lowest EC is 9.6 mS/m recorded at Luang Prabang (LLP) station in January 2020 (Annex A). Overall, the EC levels in the Mekong mainstream were highest during the Dry season months with an average Dry season concentration of 42.2 mS/m, compared to 25.0 mS/m during the Wet season months. The difference was statistically significant, with the two-sample t-test p-value of less than 0.01, indicating the significant influences of groundwater discharge and geochemical processes on the mainstream (Brunner et al., 2017; Serrano-Finetti et al., 2019; Zafar, Javed and Aly Hassan, 2022) of the Mekong River.

In addition to EC, the water quality of the Mekong River was significantly impaired by elevated levels of FC, with concentrations recorded in 2020 ranging from none-detectable level to as high as 170,000 MPN/100 mL. Among the 17 mainstream stations, the most prevalent FC impairments were recorded at Neak Loung (CNL) station with concentrations ranging from 2,600 to 170,000 MPN/100 mL. In addition to CNL, where 100% of FC data exceeded the target value of WQGH (1,000 MPN/100 mL), Kampong Cham (CKC) (2,000 to 92,000 MPN/100 mL) and Chrouy Changvar (CCC) (1,700 to 68,000 MPN/100 mL) stations also recorded FC levels of more than 1,000 MPN/100 mL at all monitoring occasions (Annex A).

Overall, FC levels in the Mekong mainstream were highest during the Wet season months when increased surface runoff occurred due to the intense monsoon rainfall (MRC, 2018). On average, the Wet season FC level was estimated at 10,307.2 MPN/100 mL at all mainstream stations (Table 3.1). In comparison, the average Dry season FC concentration for the same mainstream stations was estimated at 2,335.3 MPN/100 mL (Table 3.1). The difference was statistically significant as yielded by the normalized two-sample t-test, with a p-value of less than 0.01. FC impairment of the Mekong River water quality is expected given the current sanitation situation in the LMB, with an open defecation rate remaining high among the rural populations of Member Countries, at 80% and 24%, respectively, in Cambodia and Lao PDR (UNICEF Cambodia, 2019; UNICEF Lao PDR, 2019).

Outside of EC and FC, slight exceedances were also observed in COD and BOD levels in 2020. Along the Mekong mainstream, COD and BOD levels ranged from 2.5 to 10.6 mg/L and 1.2 to 5.4 mg/L, respectively. The highest COD concentration was recorded at Pakse (LPS) station, at 10.6 mg/L, which exceeded the target value of WQGH (5 mg/L). For BOD, the highest concentration of 5.4 mg/L was recorded at My Tho (VMT), which exceeded the target values for both WQGH (4 mg/L) and WQGA (3 mg/L).

Unlike the exceedance observed in EC and FC levels, the monitoring extent of exceedances in COD and BOD levels was more sporadic, with only 3.5% of COD data exceeding the target value of 5 mg/L (WQGH). Similarly, only 0.9% and 5.3% of BOD exceeded their respective target values of WQGH (4 mg/L) and WQGA (3 mg/L).

Water quality impairment of the Mekong mainstream with regard to DO was moderate, where 8.6% and 23.2% of DO data fell below the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively. In 2020, the lowest DO concentration of 4.8 mg/L was recorded at My Tho (VMT) station during the May sampling month. Together with VMT, My Thuan (VMH), and Tan Chau (VTC) were additional stations that recorded DO levels of less than the target value of WQGA (5 mg/L) during at least one monitoring occasion. At these three Viet Nam's Delta stations (VMT, VMH and VTC), 94% of DO data was lower than the target value of WQGH (6 mg/L). DO monitoring at these locations may needed to be carried out more frequently to capture near real-time profile of DO and facilitate the identification of potential causes and effects of low DO levels.

Table 3.1. Status of Mekong River water quality data as monitored in 2021 and compared to historical record (Blue colour marks non-compliance with WQGH or WQGA)

Periods	Seasonal	Statistical parameters	pH	TSS (mg/L)	EC (mS/m)	NO_{3-2} (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ	Chapter 1 (WQGH)		6 9	-	70 150	5.00	-	-	-	≥ 6	5.0	1,000.0	4.0
	Chapter 2 (WQGA)		6 9	-	-	5.00	-	-	-	5.0	-		3.0
2020	Dry season	Mean	7.51	24.8	42.2	0.26	0.06	0.84	0.06	7.0	2.3	2,335.3	1.2
	Wet season	Mean	7.48	96.7	25.0	0.31	0.06	0.72	0.08	6.9	2.7	10,307.2	1.1
	Total	Maximum	8.27	385.6	692.0	1.17	0.75	3.53	0.36	9.1	10.6	170,000.0	5.4
		Mean	7.49	63.2	33.0	0.29	0.06	0.78	0.07	6.9	2.5	6,600.5	1.2
		Minimum	6.43	1.8	9.6	0.01	0.00	0.10	0.01	4.8	0.4	1.1	0.1
		Std. Deviation	0.39	78.4	79.6	0.23	0.09	0.55	0.06	1.0	1.5	21,034.3	0.9
Historical	Total	Maximum	9.94	5,716	841	1.42	2.99	4.89	2.2	13.85	65	-	4.5
		Mean	7.48	144.28	20.6	0.25	0.05	0.58	0.1	7.2	2.26	-	1.19
		Minimum	3.78	0.1	1.2	0	0	0	0	2.25	0	-	0
		Std. Deviation	0.51	251.38	26.65	0.17	0.1	0.39	0.12	1.1	1.96	-	1.07

Note: The figured highlighted in blue indicate non-compliance with WQGH or WQGA.

3.1.2 Water Quality of Key Tributaries in 2021

Table 3.2 provides a descriptive statistical summary of key water quality parameters of the Mekong River tributaries in 2020. In this report, the tributary stations of the Mekong River were grouped as follows:

- The five stations in Bassac River System, which were monitored by the designated laboratories of Cambodia and Viet Nam (Table 1.2), with the results summarized and discussed in Table 3.2;
- Six tributary stations, which were monitored by the designated national laboratory of Lao PDR (Table 1.2), with the results summarized in Table 3.2;
- Five tributary stations, which were monitored by the designated national laboratory of Thailand (Table 1.2) with results summarized in Table 3.2;
- Five tributary stations located in the 3S (Se San, Sre Pok, and Se Kong) River System, which were monitored by the designated national laboratories of Cambodia and Viet Nam (Table 1.2), with results summarized in Table 3.2;
- Six tributary stations located in the Tonle Sap River System, including those located in the Tonle Sap Lake, which were monitored by the designated laboratory of Cambodia (Table 1.2), with results summarized in Table 3.2; and
- Viet Nam's Delta three canal stations, which were monitored by the designated laboratories of Viet Nam (Table 1.2), with results summarized in Table 3.2.

In 2020, the water quality at these groups of tributaries was largely in line with the water quality conditions of the Mekong, with the same five water quality parameters exceeding the target values of either the WQGH and/or WQGA. It is significant to note that EC levels were much lower than the lower limit of the WQGH (70–150 mS/m), with the exception of levels measured at Houay Mak Hiao (LHM) and Ban Chai Buri (TBC). At LHM (a tributary station in Lao PDR), EC concentrations ranged between 22.9 and 123.3 mS/m (Table 3.2), whose maximum EC value was the highest among the 48 stations of the WQMN, except for those located in the Mekong Delta (Section 3.1.1). In 2020, 64% of the EC data at LHM was higher than the lower limit of the WQGH (70 mS/m). At TBC (a tributary station in Thailand), the maximum EC value was 111 mS/m in June 2020, which was the only EC concentration at levels higher than the 70 mS/m lower limit of the WQGH. Along the Bassac River, all measured EC values were lower than the recommended target value (70–150 mS/m) for the protection of human health (Chapter 1) or WQGH. In 2020, the maximum EC value of 29.1 mS/m was recorded at VCT in June 2020, while its minimum value of 10 mS/m was recorded at CVD in November 2020. In the Bassac River, EC was not influenced by seasonality, with the average EC values for both wet and Dry seasons estimated at 18.9 mS/m. The results of the two-sample t-test confirmed that the difference in mean dry and Wet seasons concentrations was not statistically insignificant, with a p-value greater than 0.05 (0.63).

Also, in line the levels observed in the Mekong and Bassac Rivers, FC concentrations were highest among the tributaries stations located in Cambodia's national boundary. Specifically, Table 3.2 reveals that FC levels were highest among the stations located in the Tonle Sap River System, with values ranging from 1,400 140,000 MPN/100 mL. With the target value for WQGH being 1000 MPN/100 mL, 100% of FC concentrations measured among the Tonle Sap River Basin stations exceeded the target value. Slight elevated FC levels were also detected among stations of Thailand's tributaries, 3S river system, and Viet Nam's Delta canal system. However, it should be noted that due to the difficulty in meeting the sampling holding time for FC laboratory analyses, many tributary stations located far away from the national laboratories were excluded from FC monitoring. These included many tributary stations of Cambodia and Lao PDR, including the three Cambodia's 3S stations. Therefore, the FC levels reported for the 3S river system in this report only reflect the levels as monitored at Ban Don (VBD) and Pleicu (VPC) stations in Viet Nam's Central Highland. Along the Bassac River, approximately 63% of FC concentrations were greater than the target value of WQGH (1000 MPN/100 mL), with the maximum FC concentration of 120,000.00 MPN/100 mL at CKT in September 2020. At CKT, 100% of FC data was greater than the 1,000 MPN/100 mL target value of WQGH with concentrations ranging from 3,200.00 MPN/100 mL to 120,000.00 MPN/100 mL. Other than CKT, there was a similar exceedance also at CTK (Takhmao), a station immediately downstream of Phnom Phen, with 100% of measured data exceeding WQGH (1,000 MPN/100 mL). With seasonality significantly influenced (the two-sample t-test's p-value was less than 0.01), the levels of Dry season (M = 9,926.7 MPN/100 mL) and Wet season (M = 17954.6 MPN/100 mL), FC levels in the Bassac River are likely a reflection of a poor and inefficient sanitation coverage in the region (Section 3.1). By comparison, only 40% of total FC data exceeded the target value of WQGH.

For COD and BOD, the highest levels were observed in Lao PDR's tributary stations in 2020. Specifically, the maximum COD and BOD concentrations of 40.6 and 13.4 mg/L, respectively, were recorded at LHM, which in 2020 continued to receive drainage water and runoff from Lao's capital, Vientiane, with elevated levels likely resulting from the increased wastewater discharge due to increase urbanization and the reduction of natural buffer capacity of areas upstream of the monitoring station (Guédron et al., 2014; Okamoto Sharifi and Chiba, 2014; Epprecht, Bosoni and Hayward., 2018). At LMH, approximately 30% of the monitoring occasion yielded COD concentrations that were greater than the target value of WQGH (5 mg/L). Except for LMH, no other Lao PDR's tributary station recorded COD concentrations greater than 5 mg/L in 2020.

On the western side of the Mekong River where Thailand's tributary stations were monitored, 23.6% of COD concentrations exceeded the target value of WQGH (5 mg/L), and the highest COD concentration was recorded at Chiang Rai (TCR), at 8.65 mg/L. Together with TCR, Na Kae (TNK), Ubon (TUB), and Mun Khong Chiam (TMK) also recorded COD values that exceeded 5 mg/L on at least one monitoring occasion in 2020. Despite these exceedances, no station on Thailand's tributaries recorded a BOD level higher than the target values of WQGA (3 mg/L).

In the Tonle Sap Basin, the highest COD concentration of 10 mg/L was measured at Phnom Krom (CPK) in April 2020. Collectively, 30.3% of COD concentrations measured at five Tonle Sap Basin stations exceeded the target value of WQGH (5 mg/L) on at least one occasion with Kampong Loung (CKL) recorded the highest exceedance rate in 2020, at 55%. However, these exceedances did not cause the BOD level to be elevated, as the maximum BOD concentration was about 1 mg/L at Phnom Penh Port (CPP). It should be noted the only Tonle Sap Basin station not recorded COD exceedance in 2020 was Back Prea (CBP), where its highest COD concentration was 4.2 mg/L.

Further downstream in the Viet Nam's Delta canal system, the highest COD concentration was 7 mg/L, which is slight above the target value of WQGH of 5 mg/L. Among the three Viet Nam's Delta canal stations, 27.8% of COD data exceeded the target value of WQGH. All COD exceedances were measured at Tinh Bien (VTB) and Thong Binh (VTH) canals, whereas no exceedance was detected in Tu Thuong (VTT). As for BOD, the highest concentration of 5.5 mg/L was recorded at VTH in May 2020 and represented one of the three BOD concentrations that was higher than 4 mg/L (WQGH).

Along the Bassac River, the rate of COD exceedance of WQGH (5 mg/L) was similar to that recorded for the Mekong River mainstream, at 3.5%, with an average concentration of 3.6 mg/L, a value that is well within the target value of WQGH. In 2020, the maximum COD concentration was 5.9 mg/L at CTK in January 2020, while its minimum concentration was 0.7 mg/L at CKK in November 2020. The water quality of the Bassac River in terms of BOD was slightly better than that of the Mekong River mainstream (Section 3.1.1), with only about 2.2% of concentrations exceeding the target values of WQGA (3 mg/L) and no exceedance of WQGH (4 mg/L) recorded. In 2020, the highest BOD concentration of 3.2 mg/L (Table 3.2) was recorded at CTK in April 2020. Except for this maximum concentration, no other concentration was higher than the target value of WQGA.

As shown in Table 3.2, among the tributary stations of the Mekong River, excluding Bassac River, the lowest DO concentration of 3.4 mg/L was recorded Mun Khong Chiam (TMC) in August 2020. Collectively, 14.5% and 38.2% of DO concentration monitored at Thailand's tributary stations were lower than WQGA (5 mg/L) and WQGH (6 mg/L), respectively, with Na Kae (TNK) results showing the most non-compliance with WQGH, at 55%. On the eastern side of the Mekong River, five Lao PDR's tributary stations recorded DO levels of less than 6 mg/L at least during one monitoring occasion, cumulating 15.2% non-compliance rate to the WQGH. When compared to the target value of WQGA, the non-compliance rate decreased to 1.5% on one sampling occasion; the only monitoring occasion showed a minimum DO concentration of 4 mg/L, which was recorded at LHM in November 2020.

With concentrations ranging from 3.9 mg/L to 5.8 mg/L, DO levels of the three Viet Nam's Delta canal station failed to meet the target threshold of WQGH (6 mg/L). Furthermore, about 66.7% of the DO concentrations were lower than the target value of WQGA (5 mg/L), with the lowest concentration of 3.9 mg/L recorded at VTH in March 2020.

Approximately 15.8 and 40.4% of DO data of the Bassac River exceeded the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively. By comparison, about 8.6 and 23.2% of the Mekong mainstream DO data exceeded the same target values, respectively. Of the five Bassac monitoring stations, VCD recorded 100% non-compliance with the target value of WQGH (6 mg/L), of which 58% was below 5 mg/L. The lowest DO concentration of 4.6 mg/L was recorded during three sampling occasions in February and March 2020 at VCD and another in February 2020 at VCT.

In the Bassac River, levels of BOD, COD and DO were statistically influenced by seasonality; the p-values of the two-sample t-test recorded during the wet and Dry seasons were less than 0.01 for all three parameters. The differences in magnitude of the mean dry and Wet seasons concentrations of these parameters can be seen in Table 3.2. Spatial and temporal assessment of the water quality at individual tributary stations will be explored and discussed in detail in Section 3.3.

Table 3.2. Water quality status of key tributaries of the Mekong River in 2020

Periods	Statistical Parameters	pH	TSS (mg/L)	EC (mS/m)	NO_{3-2} (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ	Chapter 1 (WQGH)	6 9	-	70 150	5	-	-	-	≥ 6	5	1000	4
	Chapter 2 (WQGA)	6 9	-	-	5	-	-	-	5	-		3
Lao PDR's Tributaries	Max	8.2	551.0	123.3	3.09	0.67	6.72	0.11	8.1	40.6	790.0	13.4
	Mean	7.4	65.3	25.9	0.29	0.06	1.19	0.05	6.6	3.1	155.9	1.5
	Min	6.0	1.6	4.8	0.01	0.01	0.08	0.01	4.0	0.4	20.0	0.2
	Std. Deviation	0.4	108.1	26.9	0.66	0.12	1.36	0.03	0.7	5.1	153.2	2.7
Thailand's Tributaries	Max	8.1	263.8	110.8	0.62	0.20	1.04	0.26	8.6	8.7	16000.0	3.0
	Mean	7.2	25.5	21.8	0.15	0.05	0.50	0.06	6.4	4.4	708.3	1.0
	Min	6.4	2.3	6.7	0.00	0.00	0.13	0.02	3.4	1.4	0.0	0.3
	Std. Deviation	0.4	42.7	16.9	0.16	0.04	0.23	0.05	1.2	1.7	2179.1	0.6
3S River System	Max	8.2	116.3	12.6	1.60	0.16	2.00	0.27	8.2	4.7	7500.0	3.1
	Mean	7.3	32.4	6.9	0.31	0.04	0.50	0.09	6.7	2.5	450.8	1.7
	Min	6.1	0.6	3.3	0.02	0.00	0.05	0.01	4.8	0.5	3.0	1.1
	Std. Deviation	0.5	26.8	1.8	0.26	0.04	0.38	0.06	1.0	1.1	1561.3	0.5
Tonle Sap Basin	Max	8.0	1184.0	29.5	1.29	0.32	2.38	1.42	8.2	10.0	140000.0	1.0
	Mean	7.3	159.4	14.8	0.28	0.07	0.67	0.25	6.9	4.1	45450.0	0.8
	Min	6.6	0.7	8.2	0.03	0.00	0.17	0.00	4.3	0.8	1400.0	0.6

Periods	Statistical Parameters	pH	TSS (mg/L)	EC (mS/m)	NO_{3-2} (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ	Chapter 1 (WQGH)	6 9	-	70 150	5	-	-	-	≥ 6	5	1000	4
	Chapter 2 (WQGA)	6 9	-	-	5	-	-	-	5	-		3
	Std. Deviation	0.4	250.3	4.5	0.23	0.06	0.42	0.29	0.7	2.1	54724.3	0.1
Bassac River	Maximum	8.0	171.3	29.1	1.43	0.81	1.88	0.43	7.8	5.9	120000.0	3.2
	Mean	7.3	47.2	18.9	0.53	0.12	0.96	0.13	6.3	3.6	13210.9	1.6
	Minimum	6.5	1.7	10.0	0.11	0.00	0.22	0.01	4.6	0.7	75.0	0.6
	Std. Deviation	0.4	42.2	5.5	0.30	0.17	0.39	0.08	1.0	1.0	28589.9	0.8
Viet Nam's Canal	Max	7.9	101.0	51.9	1.58	2.17	4.39	0.67	5.8	7.0	93000.0	5.5
	Mean	7.3	44.5	24.8	0.44	0.53	1.43	0.23	4.8	4.7	3374.1	2.6
	Min	6.4	9.0	8.5	0.14	0.00	0.44	0.06	3.9	2.2	23.0	1.1
	Std. Deviation	0.4	25.0	9.7	0.25	0.58	0.97	0.16	0.4	1.0	15456.5	1.0

Note: blue colour marks non-compliance with WQGH or WQGA

3.2 CORRELATION OF KEY WATER QUALTY INDICATORS

Historical water quality data of the WQMN have allowed for relationships between key water quality parameters to be established (Table 3.3). These relationships are important in facilitating the understanding of instream behaviours of key water quality parameters (Lee et al., 2016; Ly et al., 2020). For example, NO_{3-2} levels in the Mekong appear to be positively correlated with pH, EC, TOTN, NH_4N, TOTP, COD, FC, and BOD while negatively correlated with DO and TSS (Table 3.3). The results of the Pearson's correlation analyses further revealed that the positive relationships between NO_{3-2} and EC, TOTN, TOTP, COD, and BOD were significant at a p-value of 0.01, whereas the relationship between NO_{3-2} and NH_4N was also statistically significant, at a p-value of 0.05. Similarly, the negative relationship between NO_{3-2} and DO was statistically significant at a p-value of 0.01. Hence, as EC, TOTN, COD, BOD, TOTP, and/or NH4N levels increased so did the levels of NO_{3-2}. Conversely, the decrease in NO_{3-2} levels was expected to accompany the increased DO levels. Table 3.3 also revealed that while there appeared to be relationships between NO_{3-2} and TSS (negative), pH (positive), and FC (positive), the results of the Pearson's correlation analyses indicated that these relationships were not statistically significant, with p-values greater than 0.05 (two-tailed).

Table 3.3. Correlations among key water quality parameters in the Mekong River as monitored by the WQMN from 1985 to 2020

Water Quality Parameters	pH	TSS (mg/L)	EC (mS/m)	NO_{3-2} (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
pH	--										
TSS (mg/L)	-.191**	--									
EC (mS/m)	0.064	-0.074	--								
NO_{3-2} (mg/L)	0.077	-0.023	.451**	--							
NH_4N (mg/L)	-0.123	.197**	-0.030	.185*	--						
TOTN (mg/L)	-0.030	-0.003	0.129	.222**	0.087	--					
TOTP (mg/L)	-.291**	.251**	0.025	.255**	.532**	0.108	--				
DO (mg/L)	.265**	0.026	-.249**	-.270**	-0.142	-0.135	-.429**	--			
COD (mg/L)	-.263**	.302**	.172*	.246**	.221**	0.018	.297**	-.554**	--		
FC (MPN/100 mL)	-0.049	.270**	-0.017	0.037	.181*	-0.132	-0.047	0.110	-0.022	--	
BOD (mg/L)	-.261**	0.012	.218*	.270**	.343**	.213*	.541**	-.691**	.627**	-0.124	--

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

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

3.3 SPATIOTEMPORAL VARIATIONS OF KEY WATER QUALITY INDICATORS

3.3.1 Spatial Varations of the Mekong Water Quality

3.3.1.1 Mekong River

Spatial variation of Mekong River water quality varied from indicator to indicator; indicators with statistically significant variations were detected by ANOVA for pH, EC, NO_{3-2}, NH_4N, TOTN, TOTP, COD, DO, BOD, and FC, at p-values of less than 0.01 levels. In 2020, TSS was the only key water quality indicators (except for the major cations and anions indicators)[5] that did not exhibit a statistically significant variation on a spatial scale in 2020, with an ANOVA p-value of 0.97.

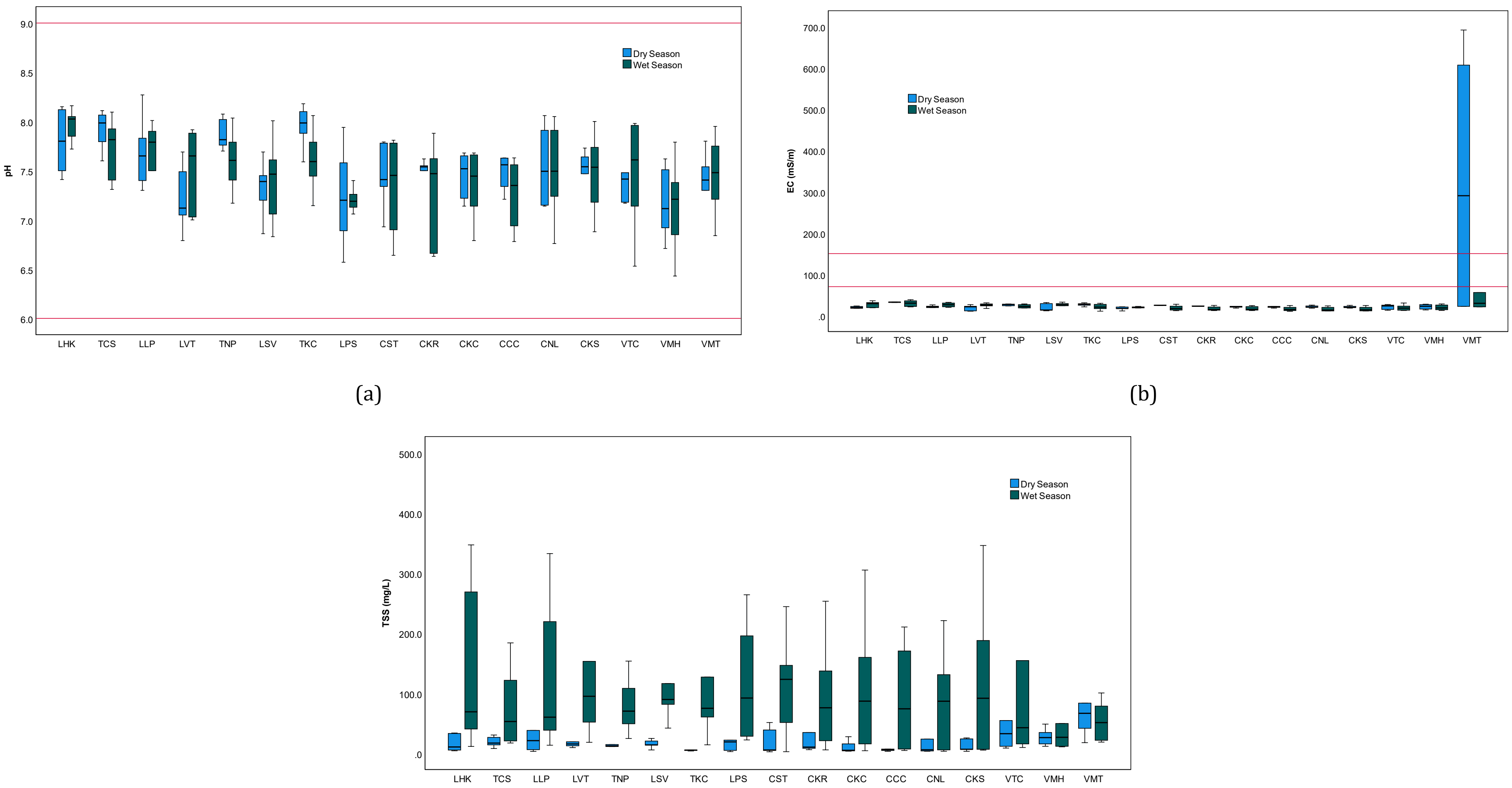
Of the 10 parameters exhibited statistically significant variations, overall downward trends were detected for pH (Figure 3.1a) and DO (Figure 3.3a), with the lowest pH and DO levels observed in the Mekong Delta region. Variations of pH and DO levels have been attributed to both natural and anthropogenic processes (Michaud, 1991; Sheldon et al., 2019; USGS, 2019). Prolonged exceedances against the target values of WQGH and WQGA could lead to severe water quality impairment, as the pH of water is known to determine the solubility and biological availability of nutrients and heavy metals (USGS, 2019). In aquatic ecosystems, pH can affect many chemical and biological processes because it affects the solubility and availability of nutrients and heavy metals in water (Swenson and Baldwin, 1965). At extremely low pH, some toxic compounds and elements from sediments may be released into the water where they can be taken up by aquatic animals or plants, and ultimately by humans through direct contact and/or human consumption of aquatic animals or plants (USEPA, 2012b). Additionally, changes in pH can also influence the availability of trace elements, iron, and nutrients, such as phosphate and ammonia in water (USEPA, 2012b).

Similarly, prolonged low DO levels can reduce the ability of the Mekong River to support aquatic life (Michaud, 1991). In the Mekong River, pH and DO levels were positively correlated with Pearson's correlation coefficient of 0.265 and at a significant p-level of 0.01 (Table 3.3). This indicates that as pH levels decreased so did the DO levels, as spatially illustrated by Figure 3.1a and Figure 3.3a. Conversely, results of Pearson's correlation analysis Table 3.3) revealed statistically significant negative relationships between pH and TOTP, COD, and BOD, whereas DO had a statistically negative relationship with EC, NO_{3-2}, TOTP, COD, and BOD. Figure 3.1 to Figure 3.3 confirm spatial patterns of the key water quality indicators where elevated levels were detected for NO_{3-2}, TOTP, COD, and BOD at stations where low pH and/or DO levels were measured. Specifically, levels of TOTP (Figure 3.2d), COD (Figure 3.3b) and BOD (Figure 3.3c) were generally highest at the three Viet Nam's Mekong Delta stations (VTC, VMH, and VMT). Correspondingly, 94.4% of the DO concentrations at these three stations were less than the target value of WQGH (6 mg/L) and may not be suitable for the protection of human health. Since 22.2% of the DO concentrations at the same three stations were less than the target value of WQGA (5 mg/L), continuous monitoring and further investigation should be carried out to ascertain any impacts on aquatic fauna that inhabit Viet Nam's Mekong Delta.

A combination of the elevated concentrations of these water quality indicators and the reduced DO and pH levels could signify increased pollution levels in the Mekong Delta region due to human activities and densely urbanized areas (MRC, 2018). Given that TOTP, COD, and BOD levels were higher during the Dry season than during the Wet season, the causes of the increased instream pollution levels may be connected to direct wastewater discharge into the Mekong River, locally and to a lesser extent, transboundary via the instream transport of nutrients and BoD pollutants.

[5] Major cations and anions are not assessed in this regional report due to their limited data availability.

Additionally, special attention should be given to the extremely elevated EC levels at VMT (My Tho) (Figure 3.1b). Along the Mekong River, EC levels historically rarely exceeded the lower limit of WQGH (70 150 mg/L). While EC concentration levels at VMT had historically been greater than 500 mS/m, these elevated values were generally measured during the high tide. In 2020, EC measurements were carried out during low tide, when the Mekong River flowed from inland to the East Sea. Nonetheless, EC concentrations were higher than 300 mS/m at four occasions, exceeding both the WQGH upper target value of 150 mS/m and the degree of consequence values for calculating the Water Quality Index for Agricultural Use for general irrigation (70 mS/m) and paddy field (200 mS/m) (Table 2.8). Given that these elevated EC levels were measured during the Dry season, the levels are of significant concern and could signify increased effects of saltwater intrusion, in combination with increasing climate variability (Reid et al., 2019; Ly et al., 2022) and the reducing flow in the Mekong mainstream (Trung et al., 2018; Hecht et al., 2019). In light of the monitoring results at VMT, further investigation and monitoring at a more frequent periods should be carried out to ascertain the increased effects of salinity intrusion in the Mekong Delta. Additional discussions on the temporal changes in EC levels at VMT are analysed and discussed in Section 3.3.1.2.



(a)

(b)

(c)

Figure 3.1. Seasonal spatial distribution of (a) pH, (b) EC and (c) TSS levels along the Mekong River from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)

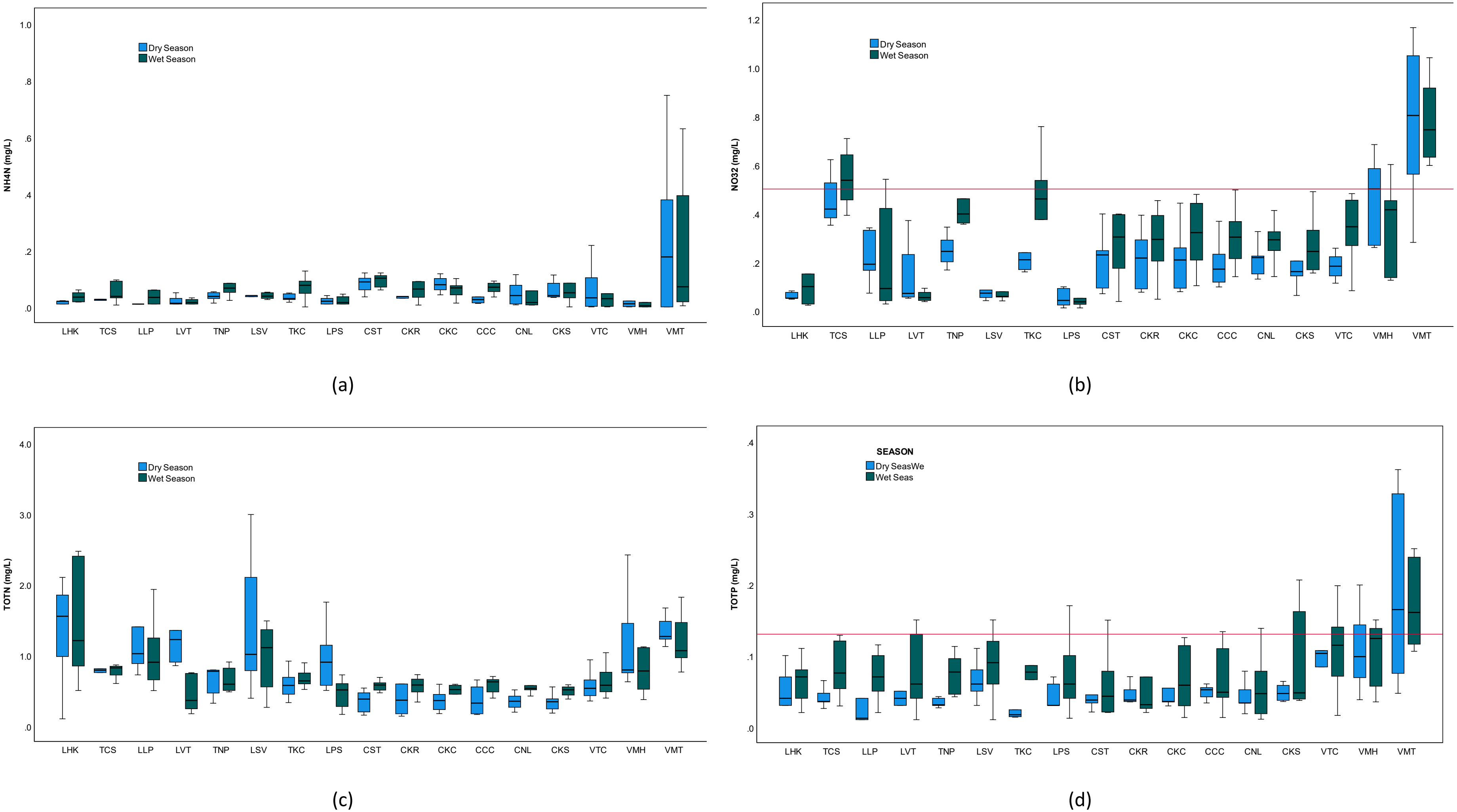


Figure 3.2. Seasonal spatial distribution of (a) $NO_{3\text{-}2}$, (b) NH_4N, (c) TOTN and (d) TOTP levels along the Mekong River from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)

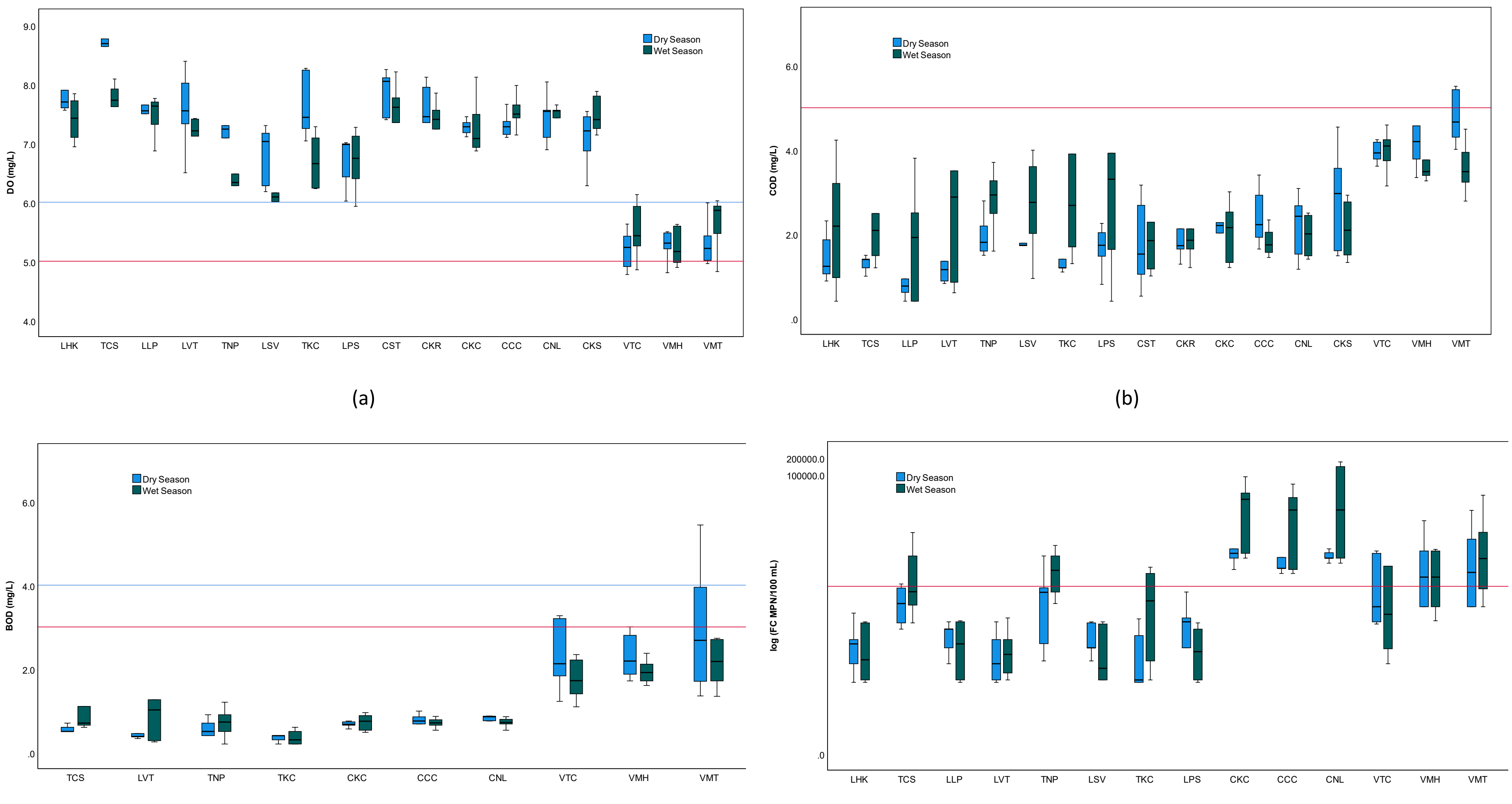


Figure 3.3. Seasonal spatial distribution of (a) DO, (b) COD, (c) BOD and (d) FC levels along the Mekong River from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)[6]

[6] BOD and FC were only monitored at stations where compliance with recommended sample holding times can be achieved.

3.3.1.2 Tributaries of the Mekong River

Spatial distributions of key water quality indicators in the Mekong's tributaries are presented in Figure 3.4 to Figure 3.6. In these figures and for spatial assessment and comparison, tributary stations were grouped into six groups based on their geographical and sub-basin locations. These six groups of tributaries are (Table 2.2):

- Lao PDR's tributary stations, which comprise LBK, LBH, LHM, LSB, LBD, and LSD;
- Thailand's tributary stations, which comprise TCR, TBC, TNK, TMK, and TUB stations;
- Tributary stations located in the 3S River System, which comprise CSP, VPC, VBD, CAM, and CPH;
- Tributary stations located in the Tonle Sap Basin, which comprise CBP, CPK, CKL, CKN, CKD, and CPP;
- Bassac River stations starting from CTK, CKK, CKT, VCD, and VCT; and
- Viet Nam's Delta canal stations of VTB, VTH, and VTT.

Among the water quality indicators examined as part of this report, no significant spatial variation was detected in the pH levels among the tributaries of the Mekong River in 2020, with all values fell within the target ranges of both WQGH and WQGA (Figure 3.4a). Other than EC levels at LHM and TBC, all EC values measured in 2020 in the tributary stations were well below 70 mS/m of the lower limit of the WQGH. At TBC, the maximum EC concentration of 110.80 mS/m was recorded in June 2020, but appears to be an outlier compared to other EC values measured at this station in 2020. At LHM, EC values in 2020 ranged from 22.9 mS/m to 123.3 mS/m, with elevated levels generally recorded during the Dry season (see Section 3.1.2).

Water quality in terms of TSS levels was highly variable from station to station, with the largest TSS ranging measured at Phnom Krom (CPK) from 8.7 mg/L in November 2020 to 1,184.0 mg/L in February 2020. Given that the maximum value was recorded during the Dry season (February 2020), instream TSS levels at Phnom Krom may have been periodically influenced by instream and/or bank activities, including inland water navigations and fishery activities (Ratha, Grenouillet and Lek, 2016; Ang and Oeurng, 2018).

Since its inception, the WQMN has monitored instream nutrient levels through NO_{3-2}, NH_4N, TOTN, and TOTP. In 2020, instream nutrient levels varied among tributaries and stations, as shown in Figure 3.5. Instream NO_{3-2} levels, which are known to be associated with point and non-point sources of urban and/or agricultural runoff (2002; Ly et al., 2020), were slightly elevated at stations receiving runoff from densely populated and/or agriculture-intensive areas including LHM, VBD, CBP, and the five Bassac stations (Figure 3.5a). Similar to those observed along the mainstream stations (Section 3.3.1.1), spatial variation of instream TOTN followed the same patterns as that of NO_{3-2}, and further confirmed the significant positive correlation between NO_{3-2} and TOTN (Section 3.2 and Table 3.3). With a spatial variation different from some extent from those of TOTN, Figure 3.5b further confirms that NH_4N is the less dominant nitrogen nutrient of the total nitrogen cycle in the tributaries of the Mekong River compared to NO_{3-2} (Figure 3.5a). For NH_4N, instream levels were highest at CTK, VTH, and VTT. Since the NH_4N concentration is generally the highest during the Dry season (see Section 3.1.2), elevated instream NH_4N levels may have been influenced by increasing the direct input of wastewater into the Mekong and its tributaries (Ratha et al., 2016) and decreasing the capacity of the river to dilute these wastewater inputs (Prathumratana, Sthiannopkao and Kim, 2008; Wilbers et al., 2014).

In 2020, total phosphorus concentrations were highly variable among tributary stations; the levels that were the highest and more variable were at stations located in the Tonle Sap River, Bassac River, and Viet Nam's canal system (Figure 3.5d). Of particular concern are the levels at Phnom Krom (CPK), which ranged from 0.01 mg/L (September 2022) to 1.42 mg/L (February 2022). At CPK, elevated levels were generally recorded during the Dry season, with an average monthly Dry season concentration of 0.66 mg/L, compared to the monthly Wet season concentration of 0.33 mg/L. It is also interesting to note that in 2020, CPK also recorded highly variable TSS concentration as discussed above and as shown in Figure 3.4c**.** Like other water quality parameters monitored under the WQMN, instream phosphorus levels can be influenced by natural processes during rock and soil weathering, which release phosphate ions and mineralize phosphate compounds that form phosphorus during instream processes (USEPA, 2012c). In addition, instream phosphorus can be introduced through surface runoff from agricultural areas and human discharges of organic waste and industrial effluents (USEPA, 2012c). Elevated instream levels at these tributary locations, especially during the Dry season, could indicate direct wastewater inputs that need to be further monitored and investigated. This is because while phosphorus is an essential nutrient for aquatic plants and animals, an increase in instream levels can cause water quality problems, including accelerated algae blooms and reduced DO levels that are essential for aquatic fauna (USEPA, 2012c).

In 2020, DO, COD, and BOD levels fluctuated from station to station and tributary to tributary; the levels of DO spatial patterns were directly opposite those of COD and BOD (Figure 3.6a, b and c). Compared to the target values WQGA and WQGH, many tributary stations recorded concentrations of DO below the threshold values of 5 and 6 mg/L, respectively. In general, stations located in Viet Nam's national boundary recorded lower DO than others, with 100% and 79.2% of DO values recorded in canal and Central Highland stations at less than 6 mg/L. In addition to the stations located in the Viet Nam, other stations with more than 20% of measured DO concentrations of less than 6 mg/L in 2020 include LMH in Lao PDR and TBC, TNK, and TUB in Thailand.

Spatially, COD and BOD follow the same patterns for stations with available data for both water quality indicators. Despite the reduced DO levels, COD and BOD concentrations of stations located in Viet Nam remained largely below the respective target values of WQGH and WQGA (Figure 3.6b and c), with the only exception being the observable elevated levels at VTH or Thong Binh station. At Thong Binh (VTH), both COD and BOD exceeded the target values of WQGH (5 mg/L and 4 mg/L, respectively) on 67% and 30% of the monitoring occasion, respectively.

FC levels were highest at CPP, CTK, and CKT, with a maximum concentration of 140,000 MPN/100 mL at CPP in September 2020. In addition to these three stations, all tributary stations in Viet Nam and four in Thailand also recorded at one FC value that exceeded the threshold value of WQGH (1,000 MPN/100 mL). In 2020, no tributary station in Lao PDR recorded FC value of greater than 1,000 MPN/100 mL (Figure 3.6d).

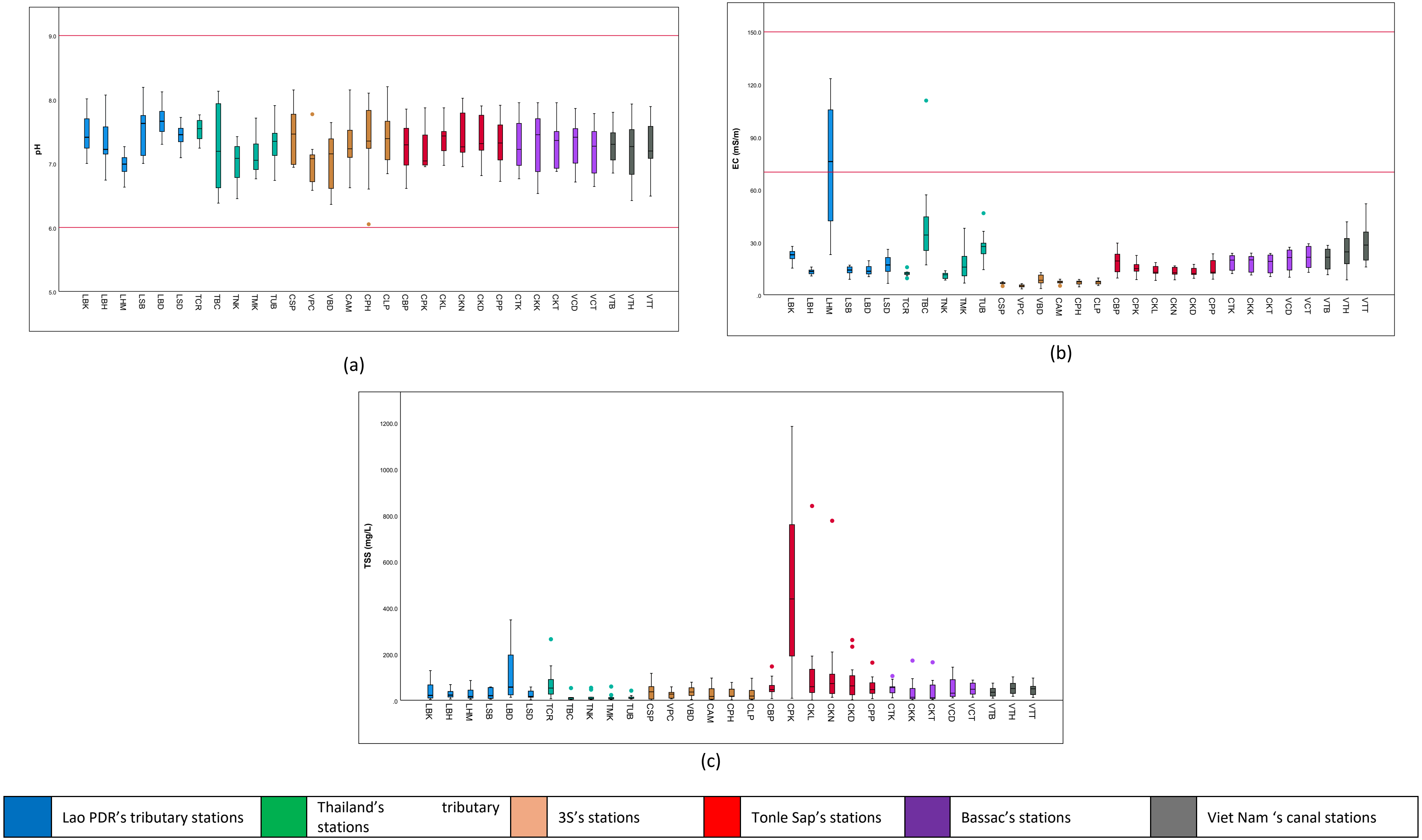


Figure 3.4. Spatial distribution of (a) pH, (b) EC and (c) TSS levels at key tributaries of the Mekong River, 2020

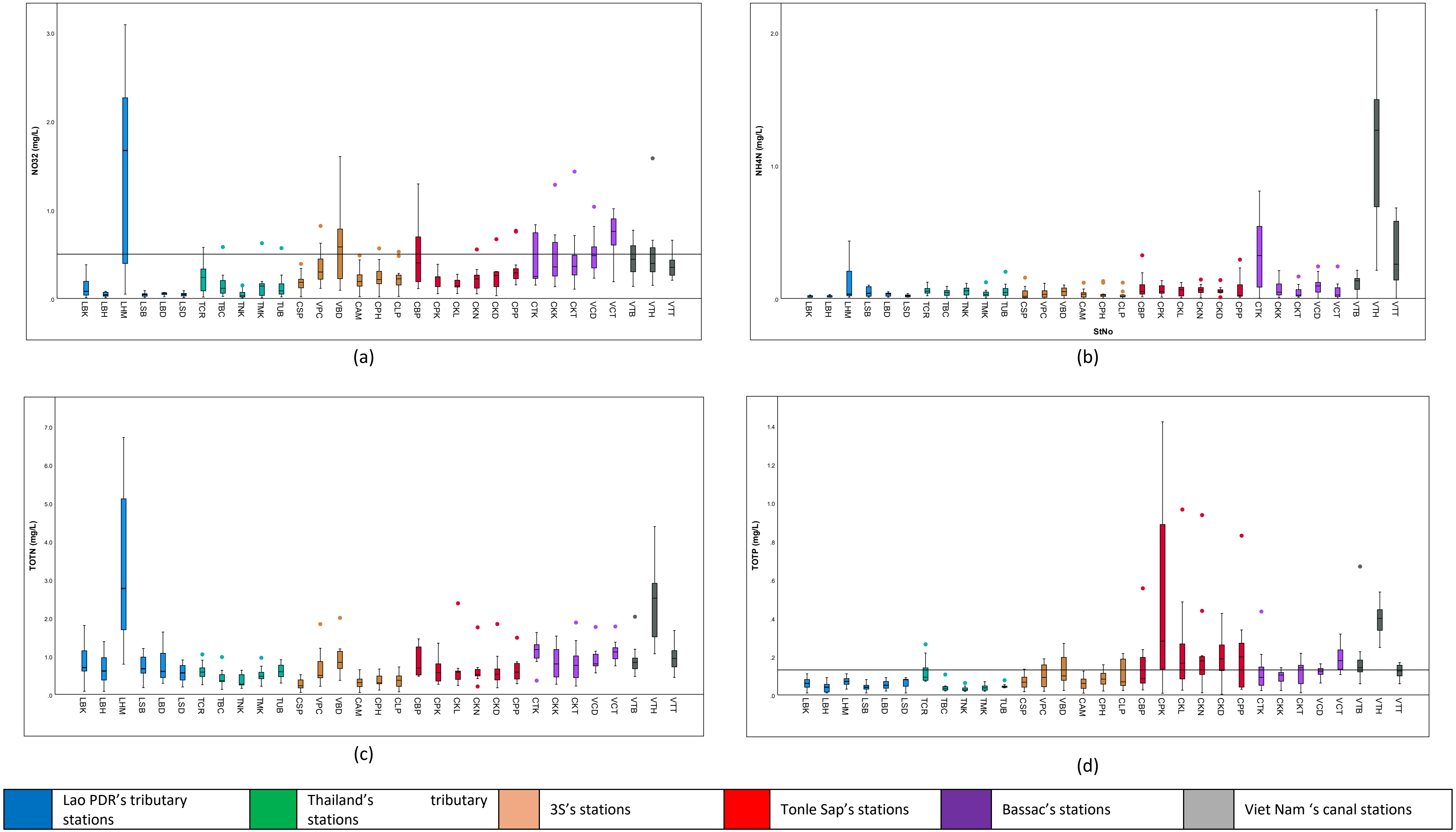


Figure 3.5. Spatial distribution of (a) NO_{3-2}, (b) NH_4N, (c) TOTN and (d) TOTP levels at key tributaries of the Mekong River, 2020

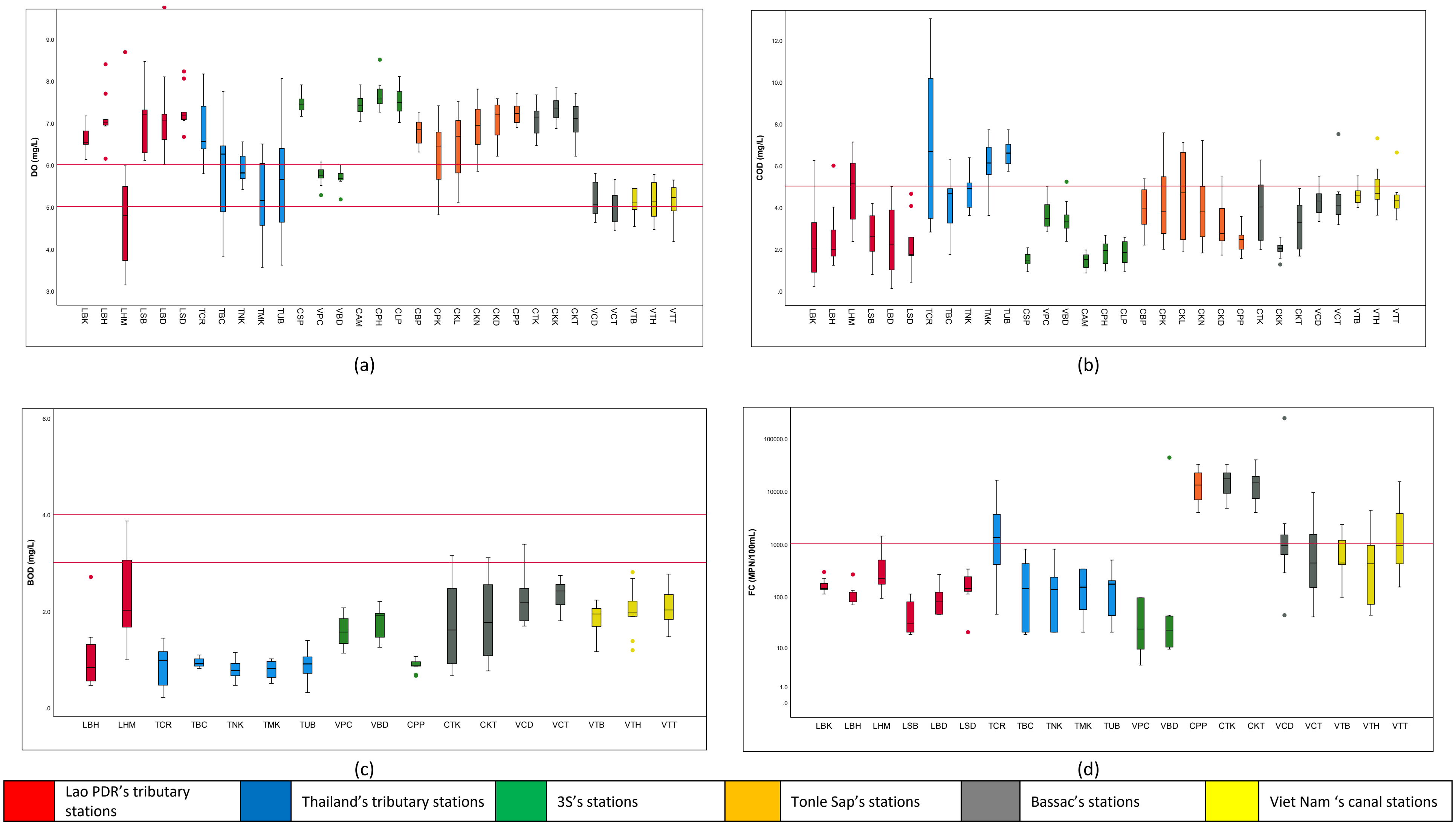


Figure 3.6. Spatial distribution of (a) DO, (b) COD, (c) BOD and (d) FC levels at key tributaries of the Mekong River, 2020

3.3.2 Temporal variations of water quality

Given that the key monitoring objective of routine WQMN in 2020 is to assess the status and trends of water quality against the objective of the PWQ (Section 1.2.2), temporal variation assessments were only carried out for water quality parameters with concentrations exceeding and/or non-compliant with the target values of WQGH (Chapter 1) and WQGA (Chapter 2). These parameters were identified and discussed in Section 3.1 and Table 3.1 and Table 3.2, and include EC, DO, COD, BOD, and FC. Their temporal variations are discussed in detail below.

3.3.2.1 Electrical Conductivity

Electrical conductivity is one of the useful water quality indicators monitored by the MRC WQMN. It provides a valuable baseline that has been used to identify any emerging effects of development on the water quality in the Mekong River. It is also the most important parameter in determining the suitability of using Mekong River water for irrigation (Gholami and Srikantaswamy, 2009). In the LMB, the EC guidelines, together with the degree of consequence, for general irrigation and paddy rice are listed in Table 1.4, Table 1.5, and Table 2.8.

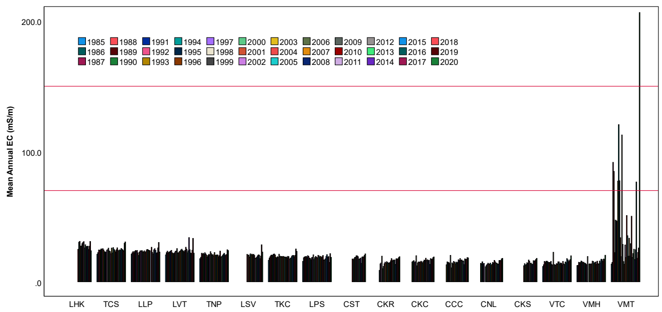
Under normal circumstance and in areas that are not affected by salinity intrusion, the Mekong and Bassac Rivers, similar to other water bodies, have constant ranges of conductivity, and therefore, any sudden and significant change in EC can be an indicator of water pollution (USEPA, 2014a; Pal et al., 2015). Similar to other water quality indicators, EC levels in a river are influenced by both natural and human-induced factors (USEPA, 2014a). Under natural conditions, EC is influenced by the amount of dissolved inorganic solids from surrounding soils and geology (Ohtani, 2013). Therefore, significant changes of EC levels in the river could indicate increased pollution levels even if its physical characteristics (i.e. colour, smell, clarity, etc.) remain the same. Wetzel (2001) states that pollution from agricultural runoff or sewage leaks can increase EC levels, while a spill of organic compound such as oil can reduce EC level.

The Mekong River and its tributaries are naturally low-salinity rivers with EC values rarely exceeding 50 mS/m when monitored during low tide. In 2020, EC levels continued to be generally lower than 70 mS/m (the lower limit of the WQGH), with the exception of a few data points at Houay Mak Hiao (LHM), Ban Chai Buri (TBC), and My Tho (VMT), where levels exceeded 70 mS/m (Sections 3.1.1 and 3.1.2).

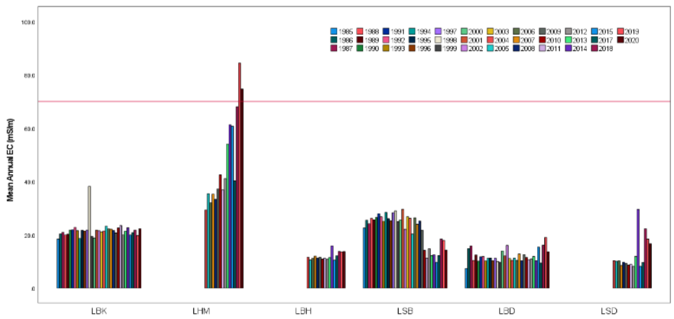
On a temporal scale, high EC had been observed in the Delta (Viet Nam's stations) during high tide due to the backwater effects of sea water, and had a maximum value of 841.0 mS/m. This maximum value was recorded at VMT in April 1998. Except for the values recorded during the high tide, annual EC levels at VMT have rarely exceeded the 150 mS/m threshold of the WQGH since the WQMN began monitoring the water quality at the station during low tide in 2005 (Figure 3.7a). Since 2005, the mean annual EC concentration at VMT has increased significantly from about 37 mS/m to 206 mS/m. The increase was determined to be statistically significant, with an ANOVA p-value of less than 0.01. The elevated EC levels could indicate the increased extent of salinity intrusion that would need to be further investigated, as discussed in Sections 3.1.1 and 3.3.1.1.

In addition to VMT, levels at LHM have also increased significantly since it was monitored in 2004 (Figure 3.7b). The mean annual average at LHM in 2005 was about 23.9 mS/m. This value has increased to 84.4 mS/m in 2019 and 74.7 mS/m in 2020. This increase was also determined to be statistically significant by ANOVA statistical analysis with the p-value of 0.01. As discussed in Sections 3.1.2 and 3.3.1.2, LHM is located on Houay Mak Hiao, a stream , of which drainage and runoff from the City of Vientiane is monitored, and may have been impacted by urbanization, as suggested by Okamoto, Sharifi and Chiba (2014) and Ly et al. (2020).

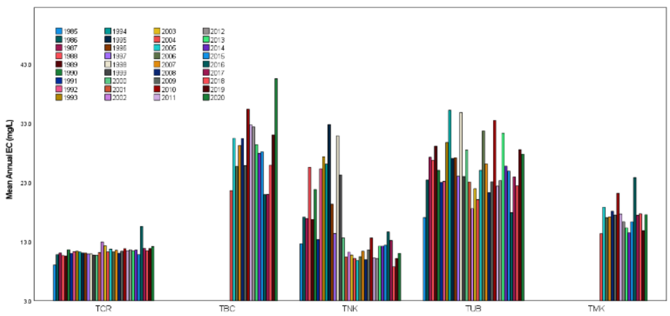
At TBC, the other station with an EC value greater than 70 mS/m in 2020, the maximum EC concentration of 110.8 mS/m was recorded in June 2020. Despite this maximum concentration, the mean annual EC concentration at TBC in 2020 was about 40.5 mS/m compared to 31 mS/m in 2019 and 21.6 mS/m in 2004, when the station was first integrated into the WQMN. While the overall temporal trends have been steadily increasing, the changes were statistically insignificant according to both ANOVA and the seasonal Mann-Kendall test, with p-values of 0.23 and 0.82, respectively.



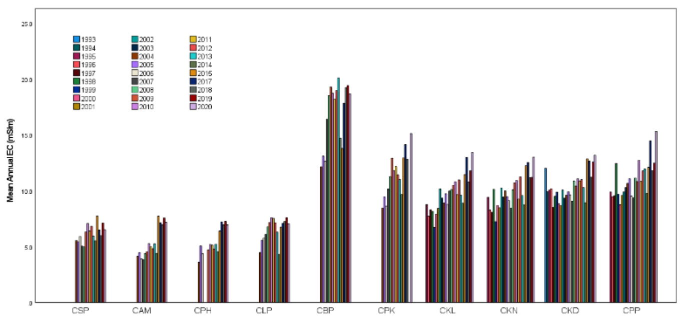
(a)



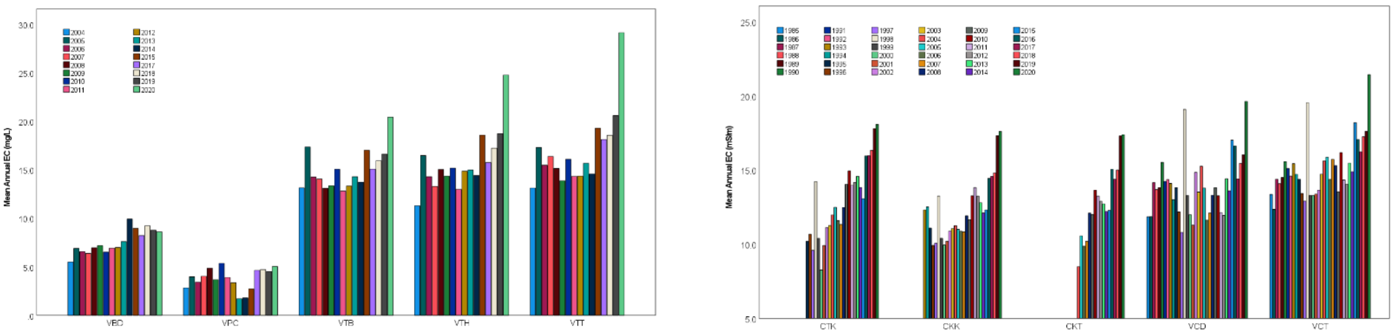
(b)



(c)



(d)



(e) (f)

Figure 3.7. Temporal variation of mean annual EC concentrations of 48 water quality monitoring stations along (a) the Mekong River; (b) Lao PDR's tributary stations; (c) Thailand's tributary stations; (d) Cambodia's tributary stations; (e) Viet Nam's tributary stations; and (f) Bassac River's stations.

3.3.2.2 Dissolved Oxygen

Temporal trends of DO at the individual 48 mainstream and tributary stations are shown in Figure 3.8. Temporal assessment of DO trends at these 48 stations by ANOVA and the seasonal Mann-Kendall test revealed that DO concentrations had decreased significantly at 14 stations, including VTC, VMH, and VMT in the mainstream, LBK of Lao PDR's tributary, TNK and TUB of Thailand's tributaries, and tributary stations in Viet Nam, including the two stations (VCD and VCT) on the Bassac River.

Of significant concern are DO levels at the eight stations located in the Viet Nam's Delta where a combined 42.7% of the measured DO concentrations were lower than the target value of WQGA (5 mg/L). When compared to the target value of WQGH, the proportion of non-compliance increased to 96.9%, i.e. only about 3% of the DO concentrations at these eight stations of Viet Nam's Delta were higher than 6 mg/L. Similar proportions of non-compliance were also recorded in 2019, with non-compliance with WQGA and WQGH at about 42.7% and 90.6%, respectively; in 2018, these figures were 46.9% and 95.8%, respectively, for non-compliance with WQGA and WQGH. By comparison, in 2005, when the eight stations were fully integrated in the current WQMN, only 1.2% and 28.6% of DO concentrations were lower than the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively.

Pearson's correlation analyses confirmed statistically significant negative relationships between instream DO and instream COD, EC, NO3-2, TOTP, COD, and BOD at p-values of 0.01; the decrease in DO levels at these stations was the result of increased levels of instream COD, EC, NO3-2, TOTP, COD, and BOD. Global studies (Poudel, Jeong and Deramus, 2010; Vandeberg et al., 2015; Schuetz et al., 2016; Yu et al., 2016; Vrebos, Beauchard and Meire, P, 2017), including many in the LMB (Poudel, Jeong and Deramus, 2010; Vandeberg et al., 2015; Schuetz et al., 2016; Yu et al., 2016; Vrebos, Beauchard and Meire, P, 2017), have linked the elevated instreams level of these water quality indicators to the increased wastewater discharge and non-point source runoff from urban, industrial, and agricultural areas. A prolonged reduction in DO levels can lead to a number of environmental issues, including a decline in the biodiversity of aquatic species (Uriarte et al., 2011; USEPA, 2012a; Nong et al., 2021). Given the current non-integration of the WQMN with other MRC environmental monitoring disciplines, including ecological health and fisheries monitoring, it is currently unclear on the extent of the effects of these reduced DO levels. Full assessment on the effects of reduced DO on aquatic species diversity should be carried out following the WQMN redesign as part of the Core River Network Monitoring.

In addition to the eight Viet Nam's Delta stations mentioned above, the two Viet Nam's Central Highland stations, Pleicu and Ban Don, should also be further investigated. It should be noted that in 2020, a combined 8.3% and 79.2% of DO concentrations at these two stations were lower than the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively. These non-compliance proportions in 2019 were 29.2% and 75%, respectively, for WQGA and WQGH. However, in 2005, when the two stations were first fully monitored monthly, all DO concentrations were higher than 6 mg/L.

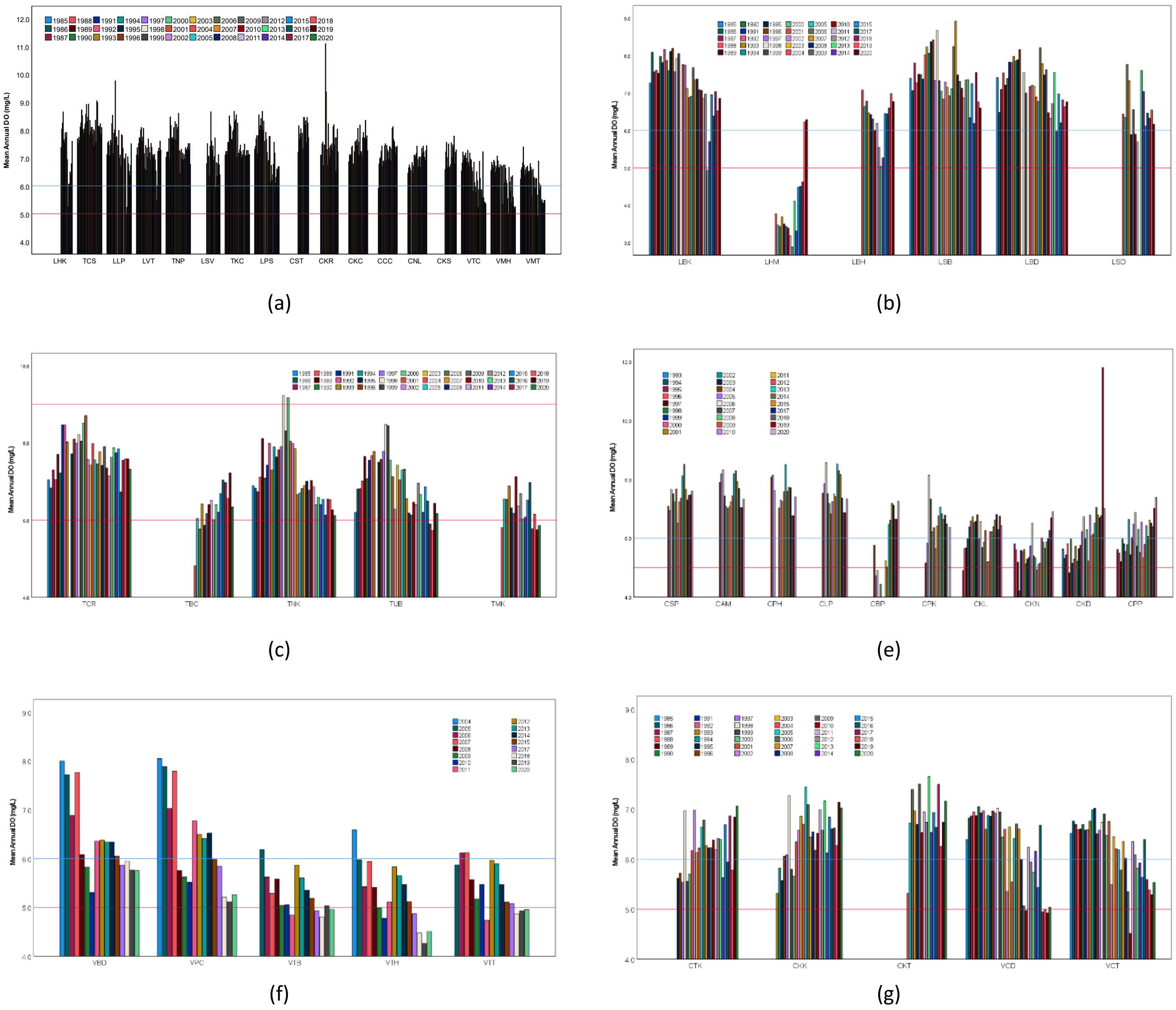


Figure 3.8. Temporal variation of mean annual DO levels of 48 water quality monitoring stations along (a) the Mekong River; (b) Lao PDR's tributary stations; (c) Thailand's tributary stations; (d) Cambodia's tributary stations; (e) Viet Nam's tributary stations; and (f) Bassac River's stations.

3.3.2.3 Chemical Oxygen Demands

COD has been widely used to measure the amount of organic and inorganic pollutants in water systems including surface water (Lee et al., 2016). Under the MRC WQMN, COD is used as a proxy for measuring organic pollution from industrial, human, and animal wastes. As such, the main purpose for monitoring COD is to assess the effects of human activities on the Mekong River's water quality. As shown in Table 2.3, potassium permanganate is used to chemically oxidize organic material in a water sample under the conditions of heat and strong acid.

Since its monitoring inception, annual mean concentrations of instream COD have fluctuated at all 48 stations, as can be seen in Figure 3.9. Assessment of overall COD temporal trends at these stations by ANOVA and the seasonal Mann-Kendall test reveal that the increases have been statistically significant at many mainstream and tributaries stations. In the mainstream, both ANOVA and Seasonal Mann-Kendall confirm that statistically significant increasing trends were detected at all but six stations. These six stations were all located in the Cambodia section of the mainstream river and exhibited decreasing COD temporal trends; however, these decreasing trends were not statistically significant, with p-values of the seasonal Mann-Kendall monotonic trend test ranging from 0.32 to 0.81.

Of the 11 mainstream stations that exhibited increasing trends, seven stations were assessed by the seasonal Mann-Kendall test to be statistically significant, at p-values of less than 0.01. These stations include TCS, LLP, LVT, TNP, VTC, VMH, and VMT, which were all located either downstream or within the urban centre and may have been influenced by urbanization and industrialization (Lee et al., 2016). Despite the increased trends, overall COD levels remained generally below the target value of WQGH, with no station recording a mean annual COD concentration of greater than 5 mg/L (Figure 3.9a).

Along the tributary stations, a number of stations recorded COD levels of concerns, including Houay Mak Hiao (LHM), Ubon (TUB), and Thong Binh Canal (VTH), whose mean annual COD concentrations exceeded the target value of the WQGH (5 mg/L) (Figure 3.9b, c, and f).

At LHM, COD levels have always been consistently elevated, although fluctuation of COD mean annual concentrations have been detected since the station was first fully integrated into the WQMN in 2005. Overall, the temporal COD trend at LHM increased slightly, with both ANOVA and the seasonal Mann-Kendall test revealing that the increased trends were statistically significant at p-values of 0.05 levels. By comparison, LHM recorded a mean annual COD concentration of 6.54 mg/L, which increased to 7.7 mg/L in 2020.

Instream COD levels at TUB also increased significantly, with both ANOVA and the seasonal Mann-Kendall test estimating the increase to be statistically significant at p-values of 0.05 and 0.01, respectively. At TUB, the annual average instream COD concentration was 2.74 mg/L in 1986 with no concentration exceeding the target value of WQGH (5 mg/L).[7] In 2020, the

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[7] TUB is one of the original stations of the WQMN, which was established in 1985, but the first full year of monitoring was carried out in 1986.

annual average COD concentration increased to 5.45 mg/L, with 36% of concentration exceeding the target value of WQGH. Since 2005, when the average annual COD concentration first exceeded the target value of WQGH, COD at TUB was highly variable, with values ranging from 0.34 mg/L to 20.6 mg/L, with an average concentration over the 2004–2020 period of about 5.31 mg/L, and a 52.4% exceedance rate of the WQGH target value (5 mg/L). By comparison, from 1985 to 2003, the average COD value was about 2.95 mg/L with 0% percent exceedance of the WQGH.

Since instream COD is a known proxy for organic pollution from industrial, human, and animal wastes (Lee and Bang, 2000; Lee et al., 2016), the increased instream COD levels at TUB may be a reflection of increased urbanization and industrialization in Houay Mak Hiao and Mun River Basins.

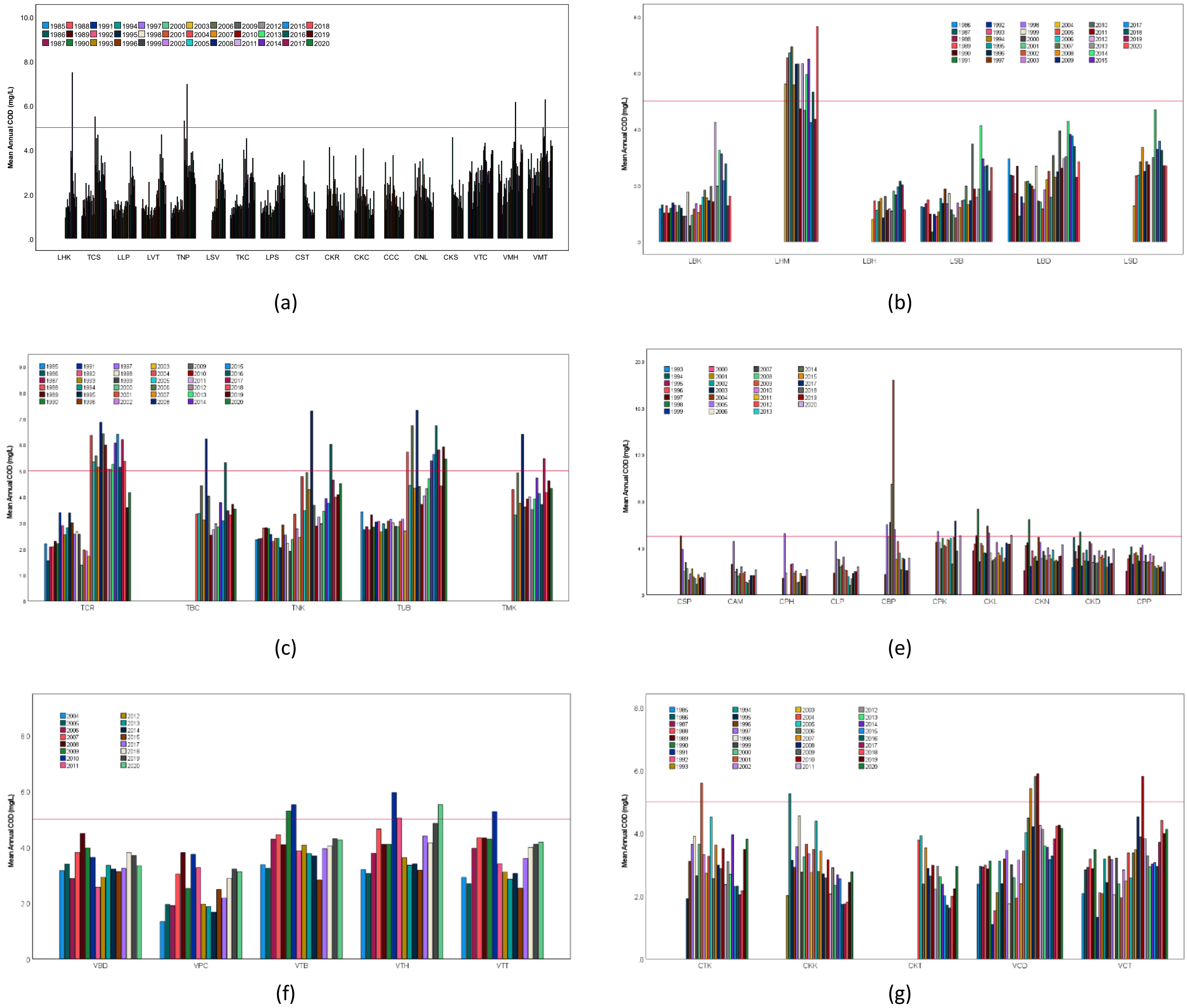

Figure 3.9. Temporal variation of mean annual COD levels of 48 water quality monitoring stations along (a) the Mekong River; (b) Lao PDR's tributary stations; (c) Thailand's tributary stations; (d) Cambodia's tributary stations; (e) Viet Nam's tributary stations; and (f) Bassac River's stations

3.4 TRANSBOUNDARY WATER QUALITY

Four transboundary water quality monitoring locations, which are assessed in this regional report, covered eight stations, including Pakse (LPS) vs. Stung Treng (CST), Pleicu (VPC) vs. Phum Phi (CPH), Kraorm Samnor (CKS) vs. Tan Chau (VTC), and Koh Thom (CKT) vs. Chau Doc (VCD). The focus of transboundary water quality issues here is on instream nutrient pollution, including NO_{3-2}, NH_4N, TOTN, and TOTP, as shown in Figure 3.10.

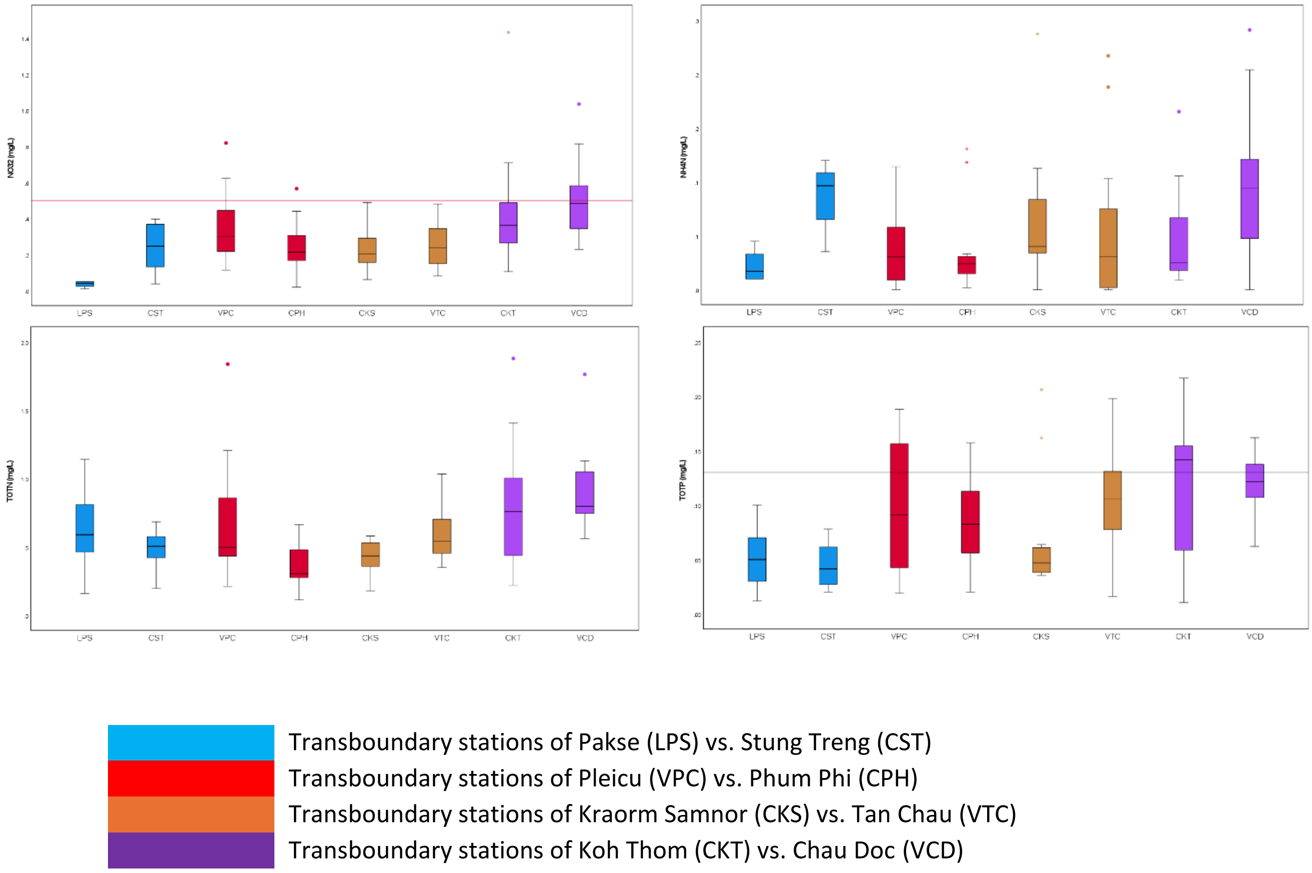

Figure 3.10. Comparisons of 2020 water quality data at the designated transboundary stations of WQMN

3.4.1 Pakse vs. Stung Treng

Figure 3.10 suggests that there may be a transboundary water quality issue between Pakse (LPS) and Strung Treng (CST) in terms of NO_{3-2} and NH_4N, whose indicator levels widely differed. The results of the t-test revealed that the differences in mean concentrations of NO_{3-2} and NH_4N at LPS and CST were statistically significant, with p-values of less than 0.01 (Table 3.4). In 2020, NO_{3-2} levels at LPS ranged from 0.01 to 0.1 mg/L, with an average concentration 0.04 mg/L (Std = 0.03). In comparison, NO_{3-2} levels measured at CST in 2020 were 0.04 to 0.4 mg/L, with an average concentration of 0.24 mg/L (Std = 0.13).

Similarly, levels of NH_4N were higher at CST than those at NO_{3-2}. At CST, NH_4N levels ranged from 0.04 to 0.12 mg/L, with an average concentration of 0.09 mg/L (Std = 0.03), whereas levels at LPS ranged from 0.01 to 0.05 mg/L, with an average of 0.02 mg/L (Std = 0.01).

In freshwater environment, NO_{3-2} and TOTP are a primary food source for algae (Poor and McDonnell, 2007; USEPA, 2014b). A limited amount of nitrate is available naturally in freshwater environment, which generally balances the nutrient needs of the aquatic ecosystem and algae growth. Persistently elevated nitrate levels, introduced through atmospheric nitrogen deposition, runoff from agricultural and urban areas, biomass degradation from impoundment, and/or erosion of soil containing nutrients, can increase the size and longevity of algal blooms (Poor and McDonnell, 2007; USEPA, 2014b).

The instream dynamics of nitrogen levels support the uptake of NO_{3-2} by algae with levels of TOTN at CST being generally lower than those at LPS. At CST, the average TOTN concentration was about 0.47 mg/L (Std = 0.17), while the level at LPS was 0.69 mg/L (Std = 0.44). It should be noted, however, that the differences in mean TOTN concentrations between the two stations were not statistically significant, with a p-value of 0.138.

Also not statistically significant was the difference in the mean TOTP concentrations at LPS (M = 0.06, Std = 0.04) and CST (M = 0.05, Std = 0.04). This indicates that the observed and/or reported algae growth downstream of the Cambodia and Lao PDR national boundary may have been driven by elevated NO_{3-2} levels and not TOTP.

The differences in levels of both NO_{3-2} and NH_4N between LPS (upstream station) and CST (downstream station) could indicate a potential transboundary water quality issue and the need for further investigation. The investigation should be carried out at CST to determine whether the sources of the elevated instream NO_{3-2} and NH_4N are localized or transported from upstream with potential transboundary consequences. Since the distance between the two stations is over 100 km, additional stations should be added between them to capture and ascertain any transboundary water quality issue.

Table 3.4. Statistical analyses of nutrient parameters monitored at LPS and CST, 2020

Indicators	Stations	Mean (mg/L)	Std. deviation	p-value
NO_{3-2}	LPS	0.04	0.03	0.000
	CST	0.24	0.13	
NH_4N	LPS	0.02	0.01	0.000
	CST	0.09	0.03	
TOTN	LPS	0.69	0.44	0.138
	CST	0.47	0.17	
TOTP	LPS	0.06	0.04	0.636
	CST	0.05	0.04	

3.4.2 Pleicu vs. Phum Phi

Pleicu (VPC) and Phum Phi (CPH) are located on the Se San River, which is part of the 3S river system and flows into the Mekong River at City of Stung Treng and downstream of the Stung Treng (CST) water quality station. Between the two stations, VPC is located in Viet Nam’s Central Highland and serves as a upstream station of the Cambodia and Viet Nam’s national boundary, whereas CPH is the downstream station located on the Cambodia side of the Se San River.

An exploratory assessment was carried out of the levels of the four nutrient water quality indicators at Pleicu (VPC) and Phum Phi (CPH), which revealed no potential transboundary water quality issue in 2020; all four indicators were higher in the upstream stations than the downstream stations (Figure 3.10). Table 3.5 provides a statistical summary of data of NO_{3-2}, NH_4N, TOTN, and TOTP at these two stations. Although concentration levels of the four water quality indicators were different at VPC and CPH, the differences were not statistically significant, with p-values ranging from 0.034 to 0.577 (Table 3.5).

Table 3.5. Statistical analyses of nutrient parameters monitored at VPC and CPH in 2020

Indicators	Stations	Mean (mg/L)	Std. deviation	p-value
NO_{3-2}	VPC	0.35	0.21	0.194
	CPH	0.25	0.15	
NH4N	VPC	0.04	0.03	0.973
	CPH	0.04	0.04	
TOTN	VPC	0.70	0.45	0.034
	CPH	0.37	0.17	
TOTP	VPC	0.10	0.06	0.577
	CPH	0.09	0.05	

3.4.3 Kaorm Samnor Vs. Tan Chau

Kaorm Samnor (CKS) and Tan Chau (VTC) monitoring stations are located on the Mekong River, with CKS on the Cambodian side and VTC on the Vietnamese side and serve as a downstream station. To assess potential transboundary water quality issues at these two stations, the analyses were carried out on four nutrient indicators (NO_{3-2}, NH_4N, TOTN and TOTP). The outcomes of these analyses are shown in Figure 3.10.

Table 3.6. Statistical analyses of nutrient parameters monitored at CKS and VTC in 2020

Indicators	Stations	Mean (mg/L)	Std. deviation	p-value
NO3-2	CKS	0.23	0.12	0.619
	VTC	0.26	0.13	
NH4N	CKS	0.07	0.06	0.678
	VTC	0.06	0.07	
TOTN	CKS	0.42	0.13	0.024
	VTC	0.60	0.21	
TOTP	CKS	0.07	0.06	0.168
	VTC	0.10	0.06	

In general, in 2020, the water quality in the Mekong River in terms of NO_{3-2}, TOTN, and TOTP was more degraded at the VTC than at the CKS. For instance, in 2020, generally higher levels of these parameters were observed at Tan Chau than at Kaorm Samnor, which indicated the possibility of a transboundary water quality issue. Statistically, t-tests revealed that there were significant differences in levels of TOTN at these two stations with p-values of 0.024 (Table 3.6). In 2020, the average TOTN concentration at CKS was 0.42 mg/L (Std = 0.13) compared to 0.60 mg/L (Std = 0.21). In addition to TOTN, levels of NO_{3-2} and TOTP were also higher at VTC than at CKS. However, the results of the t-test revealed that their mean differences were not statistically significant (Table 3.6).

3.4.4 Koh Thom vs. Chau Doc

A similar analysis was carried out at the water quality monitoring stations, Koh Thom (CKT) (on the Cambodian side of the river) and Chau Doc (VCD) (on the Vietnamese side of the river), on the Bassac River in order to explore potential transboundary water quality issues. Figure 3.10 shows a comparison of the concentrations of NO_{3-2}, NH_4H, TOTN, and TOTP recorded at CKT and VCD monitoring stations in 2020.

Table 3.7. Statistical analyses of nutrient parameters monitored at CKT and VCD, 2020

Indicators	Stations	Mean (mg/L)	Std. Deviation	p-value
NO_{3-2}	CKT	0.46	0.37	0.711
	VCD	0.51	0.23	
NH_4N	CKT	0.05	0.05	0.365
	VCD	0.09	0.07	
TOTN	CKT	0.82	0.50	0.622
	VCD	0.90	0.32	
TOTP	CKT	0.11	0.07	0.652
	VCD	0.12	0.03	

In terms of pollutant levels, Figure 3.10 shows that concentrations of NO_{3-2}, NH_4H, TOTN and TOTP were slightly higher in the downstream station (VCD) than the upstream station (CKT) in 2020. The results of the t-test, however, revealed that the differences in levels of these pollutants were not statistically significant, with p-values ranging from 0.365 to 0.711 (Table 3.7), which could indicate no significant transboundary water quality issues in relation to these parameters. However, it should be noted that levels of these nutrient indicators were slightly elevated compared to the target values used for the calculation of MRC WQI for either the protection of aquatic life or of human health (Table 2.4 and Table 2.6). For example, the average NO3-2 concentrations at CKT and VCD were 0.46 mg/L (Std = 0.37) and 0.51 mg/L (Std = 0.23), respectively. The average NO_{3-2} at VCD was slightly higher than the threshold value for WQI_{al} (0.5 mg/L), with a maximum concentration of 1.04 mg/L. These pollutants should be further monitored to ascertain not only potential transboundary water quality issues, but also to continue establishing status and trends to support the timely identification and management of sources of these pollutants.

3.5 WATER QUALITY INDICES

The water quality status of the Mekong River and its tributaries in 2020 for the protection of human health, the protection of aquatic life, and agricultural use (general irrigation and paddy irrigation) are highlighted in Table 3.8, with detailed discussions in Sections 3.5.1 to 3.5.3.

Table 3.8. Water quality for the protection of human health, the protection of aquatic life, and agricultural use of the Mekong River and its tributaries, as of 2020

Station Abbr.	Station Names	River Names	WQI_{hh}	WQIal	WQI_{ag} (general irrigation)	WQI_{ag} (paddy irrigation)
LHK	Houa Khong	Mekong	A	A	A	A
TCS	Chiang Sean	Mekong	A	B	A	A
LLP	Luang Prabang	Mekong	A	A	A	A
LVT	Vientiane	Mekong	B	A	A	A
TNP	Nakhon Phanom	Mekong	A	A	A	A
LSV	Savannakhet	Mekong	A	A	A	A
TKC	Khong Chaim	Mekong	B	A	A	A
LPS	Pakse	Mekong	B	A	A	A
CST	Stung Treng	Mekong	B	A	A	A
CKR	Kratie	Mekong	A	A	A	A
CKC	Kampong Cham	Mekong	A	A	A	A
CCC	Chrouy Changvar	Mekong	A	A	A	A
CNL	Neak Loung	Mekong	A	A	A	A
CKS	Kaorm Samnor	Mekong	A	A	A	A
VTC	Tan Chau	Mekong	A	B	A	A
VMH	My Thuan	Mekong	B	B	A	A
VMT	My Tho	Mekong	B	C	C	C
Lao PDR's Tributaries						
LBK	Ban Hatkham	Nam Ou	A	A	A	A
LBH	Ban Hai	Nam Ngum	A	A	A	A
LSD	Sedone bridge	Sedone	B	A	A	A
LSB	Se Bangfai	Se Bangfai	B	A	A	A
LBD	Ban Kengdone	Se Banghieng	B	A	A	A
LHM	Houay Mak Hiao	Houay Mak Hiao	B	B	B	A
Thailand's Tributaries						
TCR	Chiang Rai	Mae Kok	B	B	A	A
TBC	Ban Chai Buri	Song Khram	B	A	A	A
TNK	Na Kae	Kam	B	A	A	A
TUB	Ubon	Mun	B	A	A	A
TMK	Mun (Kong Chiam)	Mun	B	A	A	A
Tonle Sap River Basin						

Station Abbr.	Station Names	River Names	WQI_{hh}	WQIal	WQI_{ag} (general irrigation)	WQI_{ag} (paddy irrigation)
CBP	Backprea	Tonle Sap	A	B	A	A
CPK	Phnom Krom	Tonle Sap Lake	B	B	A	A
CKL	Kampong Luong	Tonle Sap Lake	B	B	A	A
CKN	Kampong Chnang		B	B	A	A
CKD	Prek Kdam	Tonle Sap River	B	B	A	A
CPP	Phnom Penh Port	Tonle Sap River	B	B	A	A
3S River Basin						
VPC	Pleicu	Se San	A	B	A	A
VBD	Ban Don	Sre Pok	A	B	A	A
CPH	Phum Pi	Se San	A	B	A	A
CAM	Angdoung Meas	Se San	A	A	A	A
CLP	Lumphat	Sre Pok	A	B	A	A
CSP	Siempang	Se Kong	A	A	A	A
Viet Nam's Canal						
VTT	Tu Thuong	Tu Thoung	A	B	A	A
VTH	Thong Binh	Thong Binh	C	D	A	A
VTB	Tinh Bien	Tinh Bien	B	C	A	A
Bassac River						
CTK	Takhmao	Bassac	B	B	A	A
CKK	Koh Khel	Bassac	A	B	A	A
CKT	Koh Thom	Bassac	A	B	A	A
VCD	Chau Doc	Bassac	A	C	A	A
VCT	Can Tho	Bassac	A	C	A	A

A Excellent	**A High**	**A No Restriction**
B Good	**B Good**	**B Some Restriction**
C Moderate	**C Moderate**	**C Severe Restriction**
D Poor	**D Poor**	
E Very Poor	**E Very Poor**	

3.5.1 Water Quality Index for the Protection of Aquatic Life

In 2020, water quality of the Mekong and its tributaries ranged from 'poor' to 'high' for the protection of aquatic life (Table 3.8). In the mainstream, 13 stations were rated as 'high' quality for the protection of aquatic life. With the exception of Chiang Sean (TCS), all stations located on the mainstream stretch between the Lao PDR/China national boundary to the Cambodia/Viet Nam national boundary were rated as 'high' quality for the protection of aquatic life. At these 14 stations (including TCS), a mere 2.3% (22 data points out of 953 data points) of water quality data exceeded their respective target values. Of this 2.3%, 22.7% (5 out of 22 exceedance data points) were data from TCS. At TCS, the water quality for the protection of aquatic life was rated as 'good', with about 42% of NO_{3-2} data exceeding the target value used for WQI_{al} (0.5 mg/L). No other exceedance was recorded at TCS in 2020.

Also rated as ‘good’ quality in the mainstream were water quality conditions at Tan Chau (VTC) and My Thuan (VMH). Regarding these two stations, about 12% of the combined data exceeded their respective target values. Among the indicators used for calculating WQIal, TOTP exceeded its target value of 0.13 mg/L at 29.2%, while 25% of the DO concentrations were lower than the target value for WQGA (5 mg/L).

Also in the mainstream, water quality for the protection of aquatic life at My Tho (VMT) was rated as ‘moderate’, which can be attributed to a number of exceedances and/or to non-compliance of key water quality indicators. Specifically, 91.7% of NO_{3-2} at VMT exceeded the target value of 0.5 mg/L, while 58.3% of TOTP exceeded the target value of 0.13 mg/L. Elevated levels of EC (33.3% exceedance rate) also contributed to the ‘moderate’ rating of water quality for the protection of aquatic life at My Tho.
Compared to 2019 (see Annex B), water quality for the protection of aquatic life improved slightly at three mainstream stations. including at Kratie (CKR), Kampong Cham (CKC). and Chrouy Changvar (CCC). At these three stations, the WQI_{al} rating improved from ‘good’ in 2019 to ‘high’ in 2020. Conversely, the mainstream water quality for the protection of aquatic life decreased slightly at Chiang Sean (TCS), from ‘high’ in 2019 to ‘good’ in 2020. At the other 13 mainstream stations, no change was detected in terms of water quality for the protection of aquatic life compared to the status recorded in 2019, including the status at My Tho (VMT), which was also rated as ‘moderate’ for the protection of aquatic life in 2019.

Along the tributaries of the Mekong River, water quality conditions at 11 stations were rated as ‘high’ quality for the protection of aquatic life including all but one Lao PDR’s tributary station. The only Lao PDR’s tributary station that was not rated ‘high’ quality was Houay Mak Hiao (LMH), which was rated ‘good’ quality in 2020. As discussed in Section 3.1.2, elevated EC and NO_{3-2} caused the water quality at LMH to be slightly impaired for the protection of aquatic life. At LMH, about 13% of the water quality data exceeded their respective target value in 2020. Of this 13% exceedance, 89% was caused by NO_{3-2} concentrations, which exceeded the target value of 0.5 mg/L at 72.3%.

In addition to LMH, 15 other tributary stations were also rated ‘good’ quality for the protection of aquatic life including at Chiang Rai (TCR), all six stations in the Tonle Sap River Basin, all but two stations located in the 3S River Basin, Tu Thuong Canal, and the three Cambodia’s Bassac River stations in Takhamao (CTK), Koh Khel (CKK) and Koh Thom (CKT). At these 16 stations (including LMH), where water quality was rated ‘good’ for the protection of aquatic life, elevated nutrient (NO_{3-2} and TOTP) levels were the main reason preventing their rating from reaching ‘high’ quality, with a combined 21.8% of NO_{3-2} and TOTP concentrations that exceeded their respective target values.

Along the tributaries of the Mekong River, four stations recorded water quality with ratings of ‘moderate’ level or lower (‘poor’) for the protection of aquatic life. These four stations are located in Viet Nam’s Mekong Delta, including two stations on the Bassac River (Chao Doc [VCD] and Can Tho [VCT]) and two in the canal systems (Thong Binh [VTH] and Tinh Bien [VTB]. At these stations, a combination of elevated nutrients (NO_{3-2} and TOTP) and reduced DO was the main cause for water quality impairment, with a combined 60.4% that exceeded the respective target values for the protection of aquatic life. In particular, at Thong Binh (VTH), 75% of NO_{3-2}, TOTP and DO concentrations were in non-compliance with their target values, resulting in the quality of the water for the protection of aquatic life to be rated 'poor' for 2020.

At stations where water quality conditions for the protection of aquatic were rated as either 'poor' or 'moderate', special monitoring attention should be given to increase the monitoring efforts to ascertain the duration and extent of these conditions at these stations. Additionally, investigation should be carried out to assess any potential impacts on aquatic species at these stations through multi-discipline monitoring and assessment approach as part of the core river network redesign or special investigation.

3.5.2 Water Quality Index for the Protection of Human Health

Analysis of the 2020 water quality data using the Water Quality Index for Human Health Acceptability (WQI_{hh}) reveals that water quality of the Mekong River and its tributaries for the protection of human health is still of good quality, with all but one stations rated as either 'good' or 'excellent' (Table 3.8). The only station not rated as either 'good' or 'excellent' quality was Thong Binh (VTH) station in Viet Nam's Delta, which was rated as 'moderate' quality for the protection of human health. At VTH, the main cause of water quality impairment for the protection of human health was the elevated COD levels, which exceeded the target value of WQGH (5 mg/L) on 8 of the 12 sampling occasions (about 67%). Additionally, the scale of these exceedances was between 0.04 to 0.39 mg/L, and their total extent of exceedance of 2.22 mg/L (Equation 2.5).

Among the 17 mainstream stations, 11 were rated as 'excellent' quality for the protection of human health while the remaining were rated as 'good' quality. It should be noted that the formula used does not factor into FC levels, which were highly elevated at many stations along mainstream (see Sections 3.1.1 and 3.3.1.1 for more discussion on FC). Therefore, water from the Mekong River should be directly consumed with care and in accordance with the guidelines of the World Health Organization for Drinkng Water Quality (WHO, 2011).

Compared to 2019 (Annex C), water quality of the mainstream for the protection of human health improved slightly at two stations including Nakhon Phanom (TNP) and Tan Chau (VTC). The improvement at these stations was due to the improve instream levels of COD. Conversely, water quality for the protection of human health degraded slightly at four stations when compared to the conditions in 2019. The four stations, which experienced slight water quality impairment, were Vientiane (LVT), Khong Chiam (TKC), Pakse (LPS) and Stung Treng (CST). For each of these four stations, one COD concentration exceeded the target value of WQGH (5 mg/L); the total extent of exceedance (Equation 2.5) ranged from 0.3 to 1.6 mg/L.

3.5.3 Water Quality Index for Agricultural Use

The level of impairment of the water quality for agricultural use was assessed using the MRC Water Quality Indices for Agricultural Use. While two indices were adopted by the MRC to assess the level of impairment of water quality for general irrigation and paddy rice irrigation, all indices for agricultural use can be assessed against threshold values for EC (Table 2.8).

An analysis of EC data from 2020 revealed that except for the levels recorded at My Tho (VMT) (Sections 3.1.1) and Houay Mak Hiao (LMH) (Section 3.1.2), all EC values fell within the guideline value of the Water Quality Index for General Irrigation Use of 70 mS/m. As such, water quality of the Mekong River and its tributaries was rated as 'no restriction' for general irrigation use at 46 stations (Table 3.8).

The only two stations with water quality conditions that posed restrictions to general irrigation use were VMT and LMH. At VMT, the restrictions for both general and paddy irrigation were estimated to be 'severe' in 2020 (Table 3.8), with EC levels reaching as high as 692 mS/s (March 2020). As discussed in Section 3.1.1, elevated EC levels were only recorded during the Dry season, and additional investigation and monitoring should be carried out to ascertain the extent and effects of potential salinity intrusion in the Mekong Delta. At LMH, the water quality of Houay Mak Hiao had 'some restriction' for general irrigation. However, with a maximum EC value of 123.3 mS/m (February 2020), there was no restriction for the use of Houay Mak Hiao for paddy irrigation (Table 3.8).

From 2008 to 2019, the water quality of the Mekong and Bassac River remained suitable for both general and paddy rice irrigation, with the annual WQI_{ag} ratings of mostly 'no-restriction' (Annex D). The only exception was in 2016 and 2020 at My Tho (VMT), which may have been affected by prolonged seawater intrusion (Annex D), and should be further invested as part of the regional study on the extent of salinity intrusion.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

This report provides an overall basin-wide assessment of water quality of the Mekong River and its selected tributaries in the 2020, using key water quality parameters monitored under the MRC WQMN and listed in Chapters 1 and 2 of the TGWQ as proxies for water quality. The analyses of water quality data collected from 48 water quality monitoring stations were carried out in this report using 19 key monitoring parameters and a variety of statistical analysis techniques. Of these 48 stations, 17 were located along Mekong River, five along Bassac River, and 26 in other key tributaries of the Mekong River.

Based on the assessment results of the 2020 water quality data obtained from the 48 stations of the MRC WQMN, the following key conclusions can be made on the status and spatio-temporal variation of water quality in the Mekong River and its tributaries:

- Water quality of the Mekong River and its major tributaries in 2020 varied spatially: water quality for the protection of human health was rated 'moderate' to 'excellent', while water quality for the protection of aquatic life was rated 'poor' to 'high'. With regard to the protection of aquatic life, the water quality of the Mekong and its tributaries was generally either 'good' or 'high' quality at stations located upstream of the Cambodia/Viet Nam national boundary and generally 'poor' to 'moderate' quality for stations located in the Viet Nam's Mekong Delta owing to the exceedance or non-compliance of key water quality parameters.
- Water quality at My Tho was influenced by salinity intrusion detected by elevated levels of EC in 2020, impacting the water quality for both general and paddy irrigation. The elevated EC levels, however, were only recorded during the Dry season where the Mekong River flow is generally low. Except for the restriction at VMT, water quality of the Mekong and its tributaries continued to pose no restriction for agricultural use.
- In addition to the EC levels at My Tho (VTM), impairment of water quality of the Mekong River was also detected, with elevated concentrations of FC recorded in 2020 at Neak Loung, Kampong Cham, and Chrouy Changvar stations. With the highest levels in the Mekong mainstream recorded during the Wet season months, instream FC levels may have been influenced by the current sanitation situations in the LMB, where open defecation rates remained high among rural populations of the MRC Member Countries, at 80% and 24%, respectively in Cambodia and Lao PDR (UNICEF Cambodia, 2019; UNICEF Lao PDR, 2019).
- In the tributaries of the Mekong River, water quality impairments were detected at stations located immediately downstream of urban, agricultural and/or human activities influenced areas including Houay Mak Hiao (LHM), Phnom Krom (CPK), and Thong Binh (VTH), among others. At these stations, a combination of DO, COD, BOD, FC, and nutrients water quality indicators exceeded the target values of either WQGH, WQGA, WQI_{hh}, and/or WQI_{al}.

- While water quality at all but one station was rated as either ‘good’ or ‘excellent’ for the protection of human health, elevated FC levels should be considered when utilizing the Mekong River and its tributaries as portable water, while strictly observing the World Health Organization guidelines for Drinking Water Quality (WHO, 2011).
- Using DO as a proxy, water quality of the Mekong River and its tributaries at stations located in Viet Nam’s Mekong Delta may not be suitable for the protection of human health and aquatic life; DO continued to be one of the key water quality issues for many stations in 2020.
- The reduction in DO levels was directly the result of the increased levels of EC, NO_{3-2}, TOTP, COD, or BOD. The monitoring of these parameters, together with DO, will need to be more intensive and to include a special investigation to explore potential point and non-point sources of these pollutants.

The analyses of NO_{3-2}, NH_4N, TOTN, and TOTP suggest that there may be transboundary water quality issues between Pakse (LPS) and Stung Treng (CST), i.e. there are elevated concentrations of NO_{3-2} and NH_4N at CST compared to those at LPS. Instream NO_{3-2} is known as a primary food source for algal growth and could promote the proliferation of algal growth under appropriate climate and hydrological conditions (Poor and McDonnell, 2007; USEPA, 2014b). This finding reflects the situation also observed during the periods of low flows in the LMB during 2019–2020.

4.2 RECOMMENDATIONS

In order for Member Countries’ to maintain ‘acceptable/good’ water quality of the Mekong and its tributaries their efforts must comply with the water quality parameters established in the Procedures for Water Quality and its associated Technical Guidelines (TGWQ). In addition to the 19 parameters monitored in 2020, Chapters 1 and 2 of the TGWQ provides several additional water quality indicators that need to be monitored in the near future, including heavy metal and pesticide indicators. These indicators have been included taking into consideration emerging threats to water quality, such as population growth, intensive agriculture, aquaculture and land use, navigation, irrigation, hydropower and industrialization. The latter can often lead to increased inputs of chemicals and debris that can ultimately affect the aquatic ecosystems, human health, and the suitability of the river. The monitoring of these parameters will require concerted efforts at both the national and regional levels to improve the capacities of the line agencies responsible for water quality monitoring. In addition, concerted efforts will also be required to develop cost-effective methodology for monitoring to ensure its long-term and sustainable implementation.

In recent years, specific monitoring programmes have been carried out to complement activities of the WQMN, including the Joint Environmental Monitoring Programme for Water Quality (JEM WQ) to monitor the potential effects of hydropower development on water quality, the Riverine Plastic Debris Monitoring and Assessment, and the Multi-Media Monitoring and Assessment of the Mekong Riverine. The lessons learned from the implementation of these specific water quality monitoring activities, together with the anticipated increased development in the LMB have renewed the focus on and questioning of the relevance of the current WQMN. This concerns its objectives and spatial coverage with respect to other environmental monitoring programmes, monitoring frequency for the timely detection of emerging threats, and the relevance of data to support the assessment of basin-wide development. As part of the MRC Core River Monitoring Network, the WQMN is under review to ensure its complementary to the Member Countries and the MRC's other environmental monitoring activities for meeting regional needs.

Considering the status of water quality as highlighted in this regional report, the upcoming review of the MRC Core River Monitoring Network, and the anticipated increase in development and population growth, the following are recommended for the sustainable implementation of the routine water quality monitoring under the MRC WQMN:

- Closely monitor nutrients and DO levels in the mainstream and tributary stations, including those highlighted in this report as a priority. This aims in order to ensure the timely detection of further changes so that any potential effects on human health and aquatic life can be detected and remedied in a timely manner.
- Investigate the causes and eventually the effects of water quality impairment of the aquatic fauna and ecosystem, particularly at stations where water quality was identified as either 'moderate' or 'poor' quality for the protection of aquatic life.
- Continue the development, refinement, and finalization of the detailed methodology for the long-term and cost-effective monitoring of macro and micro riverine plastic debris in the LMB as an emerging monitoring parameter, taking into consideration lessons learned from both the dry and Wet season pilots for the integration into the WQMN.
- Improve and update the water quality monitoring facilities, knowledge and skills for national laboratories by providing training programmes on various aspects of water quality monitoring and data assessment based on capacity gaps identified by the annual proficiency testing.
- Support and advocate for the integration of macro and microplastic monitoring into the routine WQMN, and strengthen the capacity of the Member Countries to implement the detailed methodology of the MRC Riverine Plastic Monitoring Programme (RPM).
- Advocate for the importance of timely submission of water quality monitoring data and report to support the timely assessment of basin-wide water quality status and trends and to support the timely preparation of basin-wide water quality reports.
- Advocate for and support the Member Countries in the timely identification and sharing of information on any water quality incident that may constitute an emergency by executing the Implementation Plan of Chapter 4 of the TGWQ on Water Quality Emergency Response and Management (WQERM).
- Explore the feasibility for monitoring additional water quality parameters listed in Chapters 1 and 2 of the TGWQ including heavy metals, as well as persistent and non-persistent organic substances.
- Through the review of the MRC Core River Monitoring Network, explore the feasibility of establishing appropriate water quality stations to support the timely detection of potential transboundary water quality issues (e.g. Lao PDR/Myanmar, Lao PDR/Cambodia, Thailand/Myanmar, Cambodia/Viet Nam, Lao PDR/Thailand, Lao PDR/China), including the feasibility of water quality monitoring by both an

automated high frequency water quality monitoring system and manual monitoring stations with parameters that are proxies to algae bloom.

- Through the recommendation of the JEM Programme, explore the possibility of integrating JEM water quality monitoring stations into the MRC WQMN or the Core River Monitoring Network to support the long-term monitoring of hydropower operational impacts and a transboundary impact assessment, including the integration of automated high frequency water quality monitoring system with the existing JEM HYCOS station at Koh Kei, downstream of the Dong Sahong hydropower project in Cambodia.
- Strengthen the capacities of the Member Countries to monitor water quality associated with development, including the installation and operational of automated, high-frequency water quality monitoring systems immediately downstream of hydropower dams, and the monitoring of hydropower-specific water quality indicators, including chlorophyll and cyanobacteria, as recommended by JEM.
- Further investigated the elevated EC levels at VMT, which might have been influenced by increasing saltwater intrusion. This investigate should be part of the planned regional study on the extent of salinity intrusion in the Mekong's Delta. Through a regional study on the extent of salinity intrusion in the Mekong Delta, ascertain the scope and extent of salinity intrusion in both the Cambodia and Viet Nam's Mekong Delta through Phase 1 data collection, and implement protocols as recommended in the detailed methodology for the long-term and cost-effective monitoring of salinity intrusion, including the provision of necessary monitoring and assessment capacities for the relevant line agencies of the Member Countries.
- Continue to support and highlight the importance of QA/QC for water quality monitoring, through the provision of training, validation of data, development and maintenance of monitoring standard operating procedures and proficiency testing.
- Advocate for and support the strengthening of cooperation among the Member Countries in water quality monitoring through technical exchanges of WQMN laboratory staff.
- Assist nationally designated laboratories in obtaining ISO/IEC 17025 certificates, which will enable laboratories to demonstrate that they operate competently and generate valid results, thereby promoting confidence in the monitoring of results nationally, regionally, and globally.

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ANNEX A – 2020 WATER QUALITY STATUS OF THE MEKONG RIVER AS MONITORED AT 17 MAINSTREAM STATIONS

Stations	Seasonal	Statistical parameters	TEMP (°C)	pH	TSS (mg/L)	COND (mS/m)	NO3-2 (mg/L)	NH4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ		Chapter 1: GPHH	-	6 9	-	70 150	5.00	-	-	-	≥ 6	5.0	1000.0	4.0
		Chapter 2: AL	-	6 9	-	-	5.00	-	-	-	> 5	-		3.0
LHK	Dry season	Mean	24.9	7.8	16.7	19.9	0.06	0.02	1.32	0.05	7.8	1.5	118.0	
	Wet season	Mean	24.5	8.0	133.8	27.1	0.14	0.04	1.44	0.07	7.4	2.2	103.0	
	Total	Maximum	28.7	8.2	347.0	35.8	0.47	0.06	2.47	0.11	8.4	4.2	330.0	
		Mean	24.7	7.9	80.6	23.8	0.11	0.03	1.38	0.06	7.6	1.9	109.8	
		Minimum	16.2	7.4	3.5	17.5	0.02	0.01	0.10	0.02	6.9	0.4	18.0	
		Std. deviation	3.7	0.3	116.5	6.3	0.13	0.02	0.77	0.03	0.4	1.1	106.4	
TCS	Dry season	Mean	21.8	7.9	18.5	31.9	0.46	0.03	0.86	0.04	8.7	1.3	582.0	0.5
	Wet season	Mean	25.7	7.7	74.3	29.4	0.54	0.05	0.78	0.08	7.6	2.2	2528.3	0.8
	Total	Maximum	28.0	8.1	183.5	38.3	0.71	0.10	1.36	0.13	9.1	4.1	9200.0	1.1
		Mean	23.9	7.8	48.9	30.6	0.51	0.04	0.81	0.06	8.1	1.8	1643.6	0.7
		Minimum	20.0	7.3	7.3	20.8	0.35	0.01	0.58	0.03	6.6	1.0	170.0	0.1
		Std. deviation	2.5	0.3	55.0	5.9	0.12	0.03	0.20	0.04	0.7	0.9	2678.7	0.3
LLP	Dry season	Mean	26.4	7.7	29.8	19.8	0.22	0.01	1.45	0.03	7.5	0.9	137.6	
	Wet season	Mean	26.1	7.7	120.2	25.9	0.20	0.03	1.02	0.07	7.5	1.8	126.3	

Stations	Seasonal	Statistical parameters	TEMP (°C)	pH	TSS (mg/L)	COND (mS/m)	NO3-2 (mg/L)	NH4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ		**Chapter 1: GPHH**	-	6 9	-	70 150	5.00	-	-	-	≥ 6	5.0	1000.0	4.0
		Chapter 2: AL	-	6 9	-	-	5.00	-	-	-	> 5	-		3.0
	Total	Maximum	28.1	8.3	332.5	31.9	0.54	0.06	3.22	0.12	8.0	3.8	240.0	
		Mean	26.2	7.7	75.0	22.8	0.21	0.02	1.21	0.05	7.5	1.4	131.5	
		Minimum	23.7	7.3	2.5	9.6	0.03	0.01	0.50	0.01	6.9	0.4	18.0	
		Std. deviation	1.5	0.3	100.7	6.0	0.17	0.02	0.78	0.04	0.3	1.1	92.3	
LVT	Dry season	Mean	25.1	7.2	17.0	18.3	0.16	0.02	1.57	0.04	7.6	1.3	83.6	0.4
	Wet season	Mean	28.4	7.5	124.5	25.0	0.06	0.02	0.44	0.08	7.1	3.3	91.7	1.2
	Total	Maximum	29.8	7.9	336.5	30.8	0.37	0.05	3.53	0.15	8.4	9.3	270.0	3.1
		Mean	26.9	7.4	75.6	22.0	0.10	0.02	0.95	0.06	7.3	2.4	88.0	0.8
		Minimum	23.7	6.8	8.8	10.4	0.04	0.01	0.17	0.01	6.0	0.6	18.0	0.3
		Std. deviation	2.1	0.4	98.2	6.6	0.10	0.01	0.94	0.04	0.6	2.5	87.4	0.8
TNP	Dry season	Mean	25.6	7.9	13.7	25.8	0.25	0.04	0.63	0.03	7.2	2.0	1071.6	0.6
	Wet season	Mean	26.8	7.6	78.8	22.4	0.44	0.06	0.65	0.08	6.4	2.8	2346.7	0.7
	Total	Maximum	29.0	8.1	153.1	28.1	0.66	0.08	0.90	0.11	7.9	3.7	5400.0	1.2
		Mean	26.3	7.7	49.2	24.0	0.35	0.05	0.64	0.06	6.8	2.4	1767.1	0.7
		Minimum	23.0	7.2	2.2	18.2	0.17	0.01	0.32	0.03	5.9	1.5	45.0	0.2

Stations	Seasonal	Statistical parameters	TEMP (°C)	pH	TSS (mg/L)	COND (mS/m)	NO3-2 (mg/L)	NH4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ		**Chapter 1: GPHH**	-	6 9	-	70 150	5.00	-	-	-	≥ 6	5.0	1000.0	4.0
		Chapter 2: AL	-	6 9	-	-	5.00	-	-	-	> 5	-		3.0
		Std. deviation	2.0	0.3	47.8	3.9	0.14	0.02	0.19	0.03	0.6	0.8	1714.9	0.3
LSV	Dry season	Mean	25.4	7.3	15.0	19.6	0.25	0.04	1.45	0.07	6.8	1.6	130.2	
	Wet season	Mean	27.1	7.4	105.7	25.5	0.18	0.04	0.98	0.09	6.1	2.7	91.2	
	Total	Maximum	31.2	8.0	218.0	32.5	1.02	0.07	2.99	0.15	7.3	4.0	230.0	
		Mean	26.3	7.4	64.5	22.8	0.21	0.04	1.19	0.08	6.4	2.2	108.9	
		Minimum	21.3	6.8	4.9	11.4	0.04	0.01	0.26	0.01	5.2	0.6	20.0	
		Std. deviation	3.2	0.4	63.8	8.0	0.34	0.02	0.80	0.04	0.6	1.0	92.3	
TKC	Dry season	Mean	25.8	7.9	5.1	26.5	0.23	0.03	0.59	0.03	7.6	1.4	89.2	0.4
	Wet season	Mean	29.3	7.6	122.4	20.7	0.49	0.07	0.67	0.08	6.7	3.5	915.8	0.4
	Total	Maximum	31.0	8.2	385.6	30.9	0.76	0.13	0.91	0.12	8.3	8.5	2200.0	0.6
		Mean	27.7	7.8	69.1	23.4	0.37	0.05	0.63	0.05	7.1	2.5	540.1	0.4
		Minimum	24.5	7.1	3.2	10.5	0.16	0.00	0.33	0.01	6.2	1.1	18.0	0.2
		Std. deviation	2.6	0.3	112.8	6.3	0.18	0.04	0.18	0.04	0.7	2.2	797.0	0.2
LPS	Dry season	Mean	27.4	7.2	20.9	17.3	0.05	0.02	0.97	0.04	6.7	1.7	273.8	
	Wet season	Mean	28.2	7.2	115.2	20.0	0.03	0.02	0.46	0.07	6.7	3.9	96.3	

Stations	Seasonal	Statistical parameters	TEMP (°C)	pH	TSS (mg/L)	COND (mS/m)	NO3-2 (mg/L)	NH4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ		**Chapter 1: GPHH**	-	6 9	-	70 150	5.00	-	-	-	≥ 6	5.0	1000.0	4.0
		Chapter 2: AL	-	6 9	-	-	5.00	-	-	-	> 5	-		3.0
	Total	Maximum	31.6	7.9	263.8	22.1	0.10	0.05	1.75	0.17	7.3	10.6	790.0	
		Mean	27.8	7.2	72.4	18.8	0.04	0.02	0.69	0.06	6.7	2.9	177.0	
		Minimum	24.7	6.6	2.1	11.1	0.01	0.01	0.16	0.01	5.9	0.4	1.1	
		Std. deviation	2.7	0.4	87.3	3.1	0.03	0.01	0.44	0.04	0.5	2.8	224.3	
CST	Dry season	Mean	29.2	7.5	19.9	25.4	0.21	0.08	0.34	0.04	7.8	1.8		
	Wet season	Mean	29.2	7.3	114.7	18.1	0.27	0.09	0.57	0.06	7.7	2.3		
	Total	Maximum	30.1	7.8	244.0	29.8	0.40	0.12	0.68	0.15	8.3	6.0		
		Mean	29.2	7.4	71.6	21.4	0.24	0.09	0.47	0.05	7.7	2.1		
		Minimum	28.5	6.6	1.8	11.7	0.04	0.04	0.15	0.02	7.4	0.5		
		Std. deviation	0.5	0.4	78.8	5.9	0.13	0.03	0.17	0.04	0.4	1.5		
CKR	Dry season	Mean	27.3	7.4	38.1	22.6	0.21	0.05	0.59	0.05	7.1	2.0		
	Wet season	Mean	29.7	7.3	94.2	16.5	0.28	0.06	0.56	0.05	7.3	2.1		
	Total	Maximum	30.5	7.9	253.0	27.0	0.45	0.11	1.71	0.15	8.1	3.7		
		Mean	28.6	7.4	68.7	19.3	0.25	0.05	0.57	0.05	7.2	2.0		
		Minimum	20.0	6.6	5.0	11.9	0.05	0.01	0.14	0.02	4.9	1.2		

Stations	Seasonal	Statistical parameters	TEMP (°C)	pH	TSS (mg/L)	COND (mS/m)	NO3-2 (mg/L)	NH4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ		**Chapter 1: GPHH**	-	6 9	-	70 150	5.00	-	-	-	≥ 6	5.0	1000.0	4.0
		Chapter 2: AL	-	6 9	-	-	5.00	-	-	-	> 5	-		3.0
		Std. deviation	2.9	0.4	81.1	5.2	0.14	0.04	0.42	0.04	0.9	0.8		
CKC	Dry season	Mean	29.7	7.4	10.5	21.8	0.22	0.08	0.36	0.05	7.3	2.2	8360.0	0.7
	Wet season	Mean	29.6	7.4	109.3	16.7	0.31	0.06	0.47	0.07	7.3	2.1	36850.0	0.7
	Total	Maximum	30.0	7.7	305.0	27.0	0.48	0.12	0.59	0.13	8.1	3.3	92000.0	1.0
		Mean	29.6	7.4	64.4	19.0	0.27	0.07	0.42	0.06	7.3	2.1	23900.0	0.7
		Minimum	29.0	6.8	2.8	12.0	0.08	0.01	0.17	0.01	6.9	1.2	2000.0	0.5
		Std. deviation	0.3	0.3	94.5	4.9	0.15	0.03	0.16	0.04	0.4	0.7	28711.8	0.2
CCC	Dry season	Mean	29.9	7.5	20.3	21.3	0.20	0.04	0.37	0.05	7.3	2.4	6240.0	0.8
	Wet season	Mean	29.6	7.3	89.6	15.9	0.30	0.07	0.58	0.07	7.5	1.8	26616.7	0.7
	Total	Maximum	30.5	7.6	210.0	25.6	0.50	0.11	0.70	0.13	8.0	3.4	68000.0	1.0
		Mean	29.7	7.4	58.1	18.3	0.25	0.05	0.48	0.06	7.4	2.1	17354.5	0.7
		Minimum	28.5	6.8	2.6	10.2	0.10	0.01	0.16	0.01	7.1	1.4	1700.0	0.5
		Std. deviation	0.7	0.3	73.5	5.0	0.13	0.03	0.20	0.03	0.3	0.6	21583.6	0.1
CNL	Dry season	Mean	29.8	7.6	24.9	21.2	0.21	0.05	0.35	0.04	7.4	2.2	3540.0	0.8
	Wet season	Mean	29.6	7.5	88.5	15.3	0.28	0.05	0.55	0.06	7.5	2.0	61466.7	0.7

Stations	Seasonal	Statistical parameters	TEMP (°C)	pH	TSS (mg/L)	COND (mS/m)	NO3-2 (mg/L)	NH4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ		**Chapter 1: GPHH**	-	6 9	-	70 150	5.00	-	-	-	≥ 6	5.0	1000.0	4.0
		Chapter 2: AL	-	6 9	-	-	5.00	-	-	-	> 5	-		3.0
	Total	Maximum	31.0	8.1	220.7	25.2	0.41	0.18	0.75	0.14	8.0	3.1	170000.0	0.9
		Mean	29.7	7.5	59.6	18.0	0.25	0.05	0.46	0.05	7.4	2.1	35136.4	0.8
		Minimum	29.0	6.8	2.7	11.0	0.13	0.01	0.19	0.01	6.9	1.2	2600.0	0.5
		Std. deviation	0.7	0.4	70.9	5.2	0.09	0.06	0.15	0.04	0.3	0.6	60596.3	0.1
CKS	Dry season	Mean	29.6	7.5	12.5	20.8	0.18	0.06	0.34	0.05	7.1	2.8		
	Wet season	Mean	29.4	7.5	121.1	15.7	0.27	0.08	0.49	0.09	7.5	2.1		
	Total	Maximum	30.3	8.0	346.0	24.7	0.49	0.24	0.58	0.21	7.9	4.5		
		Mean	29.5	7.5	71.7	18.0	0.23	0.07	0.42	0.07	7.3	2.4		
		Minimum	28.8	6.9	2.6	11.0	0.06	0.00	0.18	0.04	6.3	1.3		
		Std. deviation	0.5	0.3	107.8	4.9	0.12	0.06	0.13	0.06	0.4	1.0		
VTC	Dry season	Mean	29.0	7.4	46.0	20.9	0.18	0.06	0.57	0.10	5.2	3.9	1583.3	2.3
	Wet season	Mean	28.8	7.5	69.3	19.0	0.33	0.05	0.63	0.11	5.5	4.0	895.8	1.7
	Total	Maximum	30.4	8.0	154.0	30.3	0.48	0.22	1.03	0.20	6.1	4.6	4300.0	3.3
		Mean	28.9	7.5	57.7	19.9	0.26	0.06	0.60	0.10	5.4	4.0	1239.6	2.0
		Minimum	27.4	6.5	8.0	12.1	0.08	0.00	0.35	0.02	4.8	3.1	40.0	1.1

Stations	Seasonal	Statistical parameters	TEMP (°C)	pH	TSS (mg/L)	COND (mS/m)	NO3-2 (mg/L)	NH4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ		**Chapter 1: GPHH**	-	6 9	-	70 150	5.00	-	-	-	≥ 6	5.0	1000.0	4.0
		Chapter 2: AL	-	6 9	-	-	5.00	-	-	-	> 5	-		3.0
		Std. deviation	0.9	0.4	58.7	6.4	0.13	0.07	0.21	0.06	0.4	0.4	1553.7	0.7
VMH	Dry season	Mean	28.7	7.2	26.5	21.3	0.47	0.03	1.14	0.11	5.3	4.4	3898.3	2.3
	Wet season	Mean	29.0	7.1	28.5	19.4	0.36	0.02	0.78	0.10	5.2	3.6	2133.3	1.9
	Total	Maximum	29.9	7.8	49.0	28.1	0.68	0.13	2.42	0.20	5.6	6.2	15000.0	3.0
		Mean	28.9	7.2	27.5	20.3	0.41	0.02	0.96	0.11	5.3	4.0	3015.8	2.1
		Minimum	27.4	6.4	10.0	12.3	0.12	0.00	0.37	0.04	4.8	3.3	240.0	1.6
		Std. deviation	0.8	0.4	15.1	6.0	0.18	0.04	0.54	0.05	0.3	0.8	4122.2	0.5
VMT	Dry season	Mean	29.0	7.4	71.7	320.7	0.78	0.25	1.34	0.19	5.3	4.8	5743.3	3.0
	Wet season	Mean	28.8	7.5	53.0	92.4	0.78	0.20	1.19	0.17	5.7	3.6	10038.3	2.1
	Total	Maximum	29.8	8.0	157.0	692.0	1.17	0.75	1.82	0.36	6.0	5.5	43000.0	5.4
		Mean	28.9	7.4	62.3	206.6	0.78	0.22	1.26	0.18	5.5	4.2	7890.8	2.6
		Minimum	27.4	6.8	17.0	20.7	0.28	0.00	0.76	0.05	4.8	2.8	430.0	1.3
		Std. deviation	0.7	0.4	41.7	271.8	0.25	0.26	0.30	0.10	0.4	0.8	12785.3	1.2
Total	Dry season	Mean	27.4	7.5	24.8	42.2	0.26	0.06	0.84	0.06	7.0	2.3	2335.3	1.2
	Wet season	Mean	28.2	7.5	96.7	25.0	0.31	0.06	0.72	0.08	6.9	2.7	10307.2	1.1

Stations	Seasonal	Statistical parameters	TEMP (°C)	pH	TSS (mg/L)	COND (mS/m)	NO3-2 (mg/L)	NH4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ		**Chapter 1: GPHH**	-	6 9	-	70 150	5.00	-	-	-	≥ 6	5.0	1000.0	4.0
		Chapter 2: AL	-	6 9	-	-	5.00	-	-	-	> 5	-		3.0
	Total	Maximum	31.6	8.3	385.6	692.0	1.17	0.75	3.53	0.36	9.1	10.6	170000.0	5.4
		Mean	27.8	7.5	63.2	33.0	0.29	0.06	0.78	0.07	6.9	2.5	6600.5	1.2
		Minimum	16.2	6.4	1.8	9.6	0.01	0.00	0.10	0.01	4.8	0.4	1.1	0.1
		Std. Deviation	2.6	0.4	78.4	79.6	0.23	0.09	0.55	0.06	1.0	1.5	21034.3	0.9

ANNEX B – TEMPORAL PATTERNS OF WATER QUALITY OF THE MEKONG AND BASSAC RIVERS FOR THE PROTECTION OF AQUATIC LIFE

Station Names	Countries	Class												
		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Houa Khong	Laos	A	A	A	A	B	B	B	B	B	B	B	A	A
Chiang Saen	Thailand	A	B	B	A	B	B	A	B	B	B	B	A	B
Luang Prabang	Laos	A	A	B	A	A	B	B	B	A	B	A	A	A
Vientiane	Laos	A	A	A	A	A	B	B	A	A	A	A	A	A
Nakhon Phanom	Thailand	B	A	B	A	B	B	A	A	B	B	B	A	A
Savannakhet	Laos	A	A	A	A	A	B	B	B	A	A	B	A	A
Khong Chiam	Thailand	B	A	A	A	A	B	A	A	A	B	A	A	A
Pakse	Laos	A	A	A	A	A	B	B	B	A	A	B	A	A
Stung Trieng	Cambodia	B	B	B	B	B	B	B	B	B	A	A	A	A
Kratie	Cambodia	B	B	B	B	B	B	B	B	A	B	B	B	A
Kampong Cham	Cambodia	B	B	B	B	B	B	A	B	A	A	B	B	A
Chrouy Changvar	Cambodia	B	B	B	B	B	B	B	B	A	A	B	B	A
Neak Loung	Cambodia	B	B	B	B	B	B	B	B	A	A	B	A	A
Kaorm Samnor	Cambodia	B	B	B	B	B	B	B	B	A	A	B	A	A
Tan Chau	Viet Nam	B	B	B	B	B	B	B	B	B	A	B	B	B
My Thuan	Viet Nam	B	B	B	B	B	B	B	B	B	B	B	B	B
My Tho	Viet Nam	C	C	C	C	B	C	C	C	D	C	B	C	C

A High
B Good
C Moderate
D Poor
E Very Poor

APPENDIX C - TEMPORAL PATTERNS OF WATER QUALITY OF THE MEKONG AND BASSAC RIVERS FOR THE PROTECTION OF HUMAN HEALTH

Station Names	Countries	Class												
		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Houa Khong	Lao PDR	A	A	B	A	B	B	C	A	A	A	B	A	A
Chiang Saen	Thailand	B	B	B	A	B	B	B	B	B	B	B	A	A
Luang Prabang	Lao PDR	A	A	B	A	B	A	B	B	B	A	B	A	A
Vientiane	Lao PDR	A	A	B	A	B	B	B	B	B	A	A	A	B
Nakhon Phanom	Thailand	B	B	B	B	B	B	B	B	B	B	B	B	A
Savannakhet	Lao PDR	A	A	A	A	B	B	C	B	B	A	A	A	A
Khong Chiam	Thailand	B	B	B	A	B	B	B	B	B	B	B	A	B
Pakse	Lao PDR	B	A	A	A	A	B	A	B	B	A	A	A	B
Stung Trieng	Cambodia	B	A	A	A	A	A	A	A	A	A	A	A	B
Kratie	Cambodia	B	A	A	A	A	A	A	A	A	A	A	A	A
Kampong Cham	Cambodia	B	A	A	A	A	A	A	B	A	A	A	A	A
Chrouy Changvar	Cambodia	B	A	A	A	A	A	A	A	A	A	A	A	A
Neak Loung	Cambodia	B	A	A	A	A	A	A	B	A	A	A	A	A
Kaorm Samnor	Cambodia	B	A	A	A	B	A	A	B	A	A	A	A	A
Tan Chau	Viet Nam	B	C	B	B	A	A	A	A	A	A	B	B	A
My Thuan	Viet Nam	B	B	C	A	A	B	A	A	A	B	B	A	B
My Tho	Viet Nam	B	C	C	B	B	B	B	A	B	B	B	A	B

A Excellent
B Good
C Moderate
D Poor
E Very Poor

APPENDIX D - TEMPORAL PATTERNS OF WATER QUALITY OF THE MEKONG AND BASSAC RIVERS FOR THE AGRICULTURAL USE – GENERAL IRRIGATION

Station Names	Countries	Class												
		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Houa Khong	Laos	A	A	A	A	A	A	A	A	A	A	A	A	A
Chiang Saen	Thailand	A	A	A	A	A	A	A	A	A	A	A	A	A
Luang Prabang	Laos	A	A	A	A	A	A	A	A	A	A	A	A	A
Vientiane	Laos	A	A	A	A	A	A	A	A	A	A	A	A	A
Nakhon Phanom	Thailand	A	A	A	A	A	A	A	A	A	A	A	A	A
Savannakhet	Laos	A	A	A	A	A	A	A	A	A	A	A	A	A
Khong Chiam	Thailand	A	A	A	A	A	A	A	A	A	A	A	A	A
Pakse	Laos	A	A	A	A	A	A	A	A	A	A	A	A	A
Stung Trieng	Cambodia	A	A	A	A	A	A	A	A	A	A	A	A	A
Kratie	Cambodia	A	A	A	A	A	A	A	A	A	A	A	A	A
Kampong Cham	Cambodia	A	A	A	A	A	A	A	A	A	A	A	A	A
Chrouy Changvar	Cambodia	A	A	A	A	A	A	A	A	A	A	A	A	A
Neak Loung	Cambodia	A	A	A	A	A	A	A	A	A	A	A	A	A
Kaorm Samnor	Cambodia	A	A	A	A	A	A	A	A	A	A	A	A	A
Tan Chau	Viet Nam	A	A	A	A	A	A	A	A	A	A	A	A	A
My Thuan	Viet Nam	A	A	A	A	A	A	A	A	A	A	A	A	A
My Tho	Viet Nam	A	A	A	A	A	A	A	A	B	A	A	A	C

A No Restriction
B Some Restriction
C Severe Restriction

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