MEKONG RIVER COMMISSION
For Sustainable Development

# 2021 LOWER MEKONG Water Quality MONITORING REPORT

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# 2021 LOWER MEKONG WATER QUALITY MONITORING REPORT

August 2022

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Mekong River Commission
Documentation and Learning Centre
184 Fa Ngoum Road, Unit 18, Ban Sithane Neua, Sikhottabong District, Vientiane 01000, Lao PDR
Telephone: +856-21 263 263 | E-mail: mrcs@mrcmekong.org | www.mrcmekong.org

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# AUTHORS

*Project management:*
Mr. Phetsamone Khanophet, Director of Environmental Management Division, the Mekong River Commission Secretariat

Mr Theerawat Samphawamana, Director of Planning Division;
Mr Sophearin Chea, Chief River Basin Planner;
Dr Sinxay Vongphachanh, Agriculture and Irrigation Specialist

*Technical experts:*
Dr. Kongmeng Ly, Ecosystem and Wetland Specialist, Environmental Management Division, the Mekong River Commission Secretariat;
Dr. So Nam, Chief Environment Officer, Environmental Management Division, the Mekong River Commission Secretariat;
Dr. Phan Nam Long, Water Quality Officer, Environmental Management Division, the Mekong River Commission Secretariat

*International technical experts:*
Dr Kazunori Minamikawa, Senior Researcher, Japan International Research Center for Agricultural Sciences, Japan

*Contributors:*
National Mekong Committee Secretariats of Cambodia, Lao PDR, Thailand and Viet Nam
The Department of Hydrology and River Works, Ministry of Water Resources and Meteorology, Cambodia;
The Natural Resources and Environment Research Institute, Ministry of Natural Resources and Environment, Lao PDR;
The Water Quality Analysis Division, Bureau of Research Development and Hydrology, 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
Meas Sophal, Environment and Protected Areas Management Specialist, Ministry of Environment, Cambodia;

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **AL** | Guidelines for the Protection of Aquatic Life |
| **ANOVA** | Analysis of Variance |
| **BOD** | Biochemical Oxygen Demand |
| **COD** | Chemical Oxygen Demand |
| **CODMN** | Chemical Oxygen Demand Analysed using the Permanganate Oxidation Method |
| **DO** | Dissolved Oxygen |
| **DHRW** | Department of Hydrology and River Work |
| **EC** | Electrical Conductivity |
| **ED** | Environmental Management Division |
| **FC** | Faecal Coliform |
| **JEM** | Joint Environmental Monitoring |
| **HFWQ** | High Frequency Water Quality Monitoring System |
| **HH** | Guidelines for the Protection of Human Health |
| **HYCOS** | Hydrological Cycle Observing System |
| **IP** | Implementation Plan |
| **ISO** | International Organization for Standardization |
| **LMB** | Lower Mekong Basin |
| **MCs** | Member Countries |
| **MONRE** | Ministry of Natural Resources and Environment |
| **MOWRAM** | Ministry of Water Resources and Meteorology |
| **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 |
| **PT** | Proficiency Testing |
| **PWQ** | Procedures for Water Quality |

| | |
|---|---|
| **QA/QC** | Quality Assurance/Quality Control |
| **RPM** | Riverine Plastic Monitoring Programme |
| **SM** | Standard Methods for Water and Wastewater Examination |
| **SMK** | Seasonal Mann-Kendall |
| **TGWQ** | Technical Guidelines for the Implementation of the Procedures for Water Quality |
| **ToR** | Terms of Reference |
| **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

The Mekong River Commission's (MRC) Water Quality Monitoring Network (WQMN), which was established in 1985, has provided a continuous time series of water quality data on 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 carried out to support the implementation of the Procedures of 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 support from the Environmental Management Division of the Mekong River Commission Secretariat (MRCS).

In 2021, routine water quality monitoring of the Mekong River and its tributaries continued conducted at 48 stations, of which 17 were located along the Mekong mainstream and 31 in key tributaries of the Mekong River, including five stations along the Bassac River. At each station, 19 water quality parameters were monitored, of which 13 were considered routine and were monitored monthly. The other six parameters (i.e. major anions and cations) were also monitored with different frequencies among the MCs: Monthly for Thailand and Cambodia, April – October for Lao PDR and in March, April, August and September for Viet Nam.

This report contains the assessment of the status, spatial, and temporal trends of 17 stations along the Mekong River and 31 stations along key tributaries. The key tributaries are classified into Lao PDR's (six stations), Thailand's tributaries (five stations), 3S river system (five stations), Tonle Sap River System (six stations) and Viet Nam's Delta (three stations).

The analyses of status, spatial, and temporal trends were carried out using a combination of statistical techniques and MRC Water Quality Indices (WQI). The water quality status in 2021 was compared with the MRC Water Quality Guidelines for Human Health and for the Protection of Aquatic Life. Annual spatial analyses of key water quality indicators were performed to identify their instream concentration changes in space. The key water quality indicators include pH, electrical conductivity (EC), total suspended solids (TSS), nitrate-nitrite ($NO_{3-2}$), ammonium (NH4N), total nitrogen (TOTN), total phosphorus (TOTP), dissolved oxygen (DO), chemical oxygen demand (COD) and biochemical oxygen demand (BOD). The temporal trend at each station using monthly data was carried out to determine its trend since it was monitored until 2021. The temporal analyses focused on EC, DO and COD. Potential transboundary water quality issues were also examined for nutrient parameters ($NO_{3-2}$, $NH_4N$, TOTN, and TOTP), DO and COD at four transboundary sites including Paske vs. Stung Treng, Pleicu vs. Phum Phi, Kraorm Samnor vs. Tan Chau, and Koh Thom vs. Chau Doc. Statistical techniques applied to figure out the statistically significant spatial and temporal trend of water quality in 2021 were one-way analysis of variance (ANOVA), Seasonal Mann-Kendall, and independent T-test. The Pearson's correlation was also performed for water quality data in 2021 to understand the relationships among key water quality parameters. The MRC WQI was used to quantitatively assess the suitability of water quality conditions for protecting human health, aquatic life and various agricultural uses.

The results of 2021 water quality indicated that Faecal coliform (FC) is elevated at many mainstream and tributaries stations. DO and nutrient parameters mostly showed good water quality, of which concentrations were below the threshold values of the protection of human health and aquatic life.

Water quality at 48 stations indicated good quality with respect to the target values of focused parameters in WQGH and WQGA. Statistical analysis indicated that the water quality in the Lower Mekong River Basin is significantly spatial variation.

In 2021, 44 stations were rated either “good” or “excellent” for the Water Quality Index for the Protection of Human Health. The other four stations were rated “moderate” water quality located in the tributaries of Lao PDR (LHM) and Thailand (TUB and TMK), and Mekong mainstream in Viet Nam (VMT), where instream water quality continued to be periodically affected by elevated electrical conductivity and/or COD levels and reduced DO levels.

Regarding the Water Quality Index for the Protection of Aquatic Life, 45 stations was rated either “good” or “high” quality. Three stations were rated “moderate” quality located in Viet Nam (VMT, VTH, and VCT), which was occasionally observed elevated nutrient concentrations and/or reduced DO levels.

The influence of salinity intrusion continued to be seasonally observed at VTM in 2021 but was less than 2020. This was also the only station in the mainstream with “some restriction” for general irrigation in 2021.

The assessment of potential transboundary water quality issue showed statistically significant of such potential at CKT and VCD, CKS and VTC.

Overall, according to MRC WQI, the water quality in 2021 kept maintaining the “acceptable/good” in the Lower Mekong Basin (LMB). However, the impact of saltwater intrusion is consecutively observed in the delta of LMB in 2020 and 2021, and thus, proactive solutions are required for the adaptation of the issue.

# 1. INTRODUCTION

## 1.1 Background

Ranked as 12th longest at about 4,880 km and 8th in terms of mean annual discharge at its mouth at about 14,500 m3/s (Mekong River Commission, 2019), 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 km2, 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 km2), and the Lower Mekong Basin which comprises an area downstream of the Chinese border with Lao PDR.

The Lower Mekong 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 km2, 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 (Mekong River Commission, 2019).

According to the 2018 State of the Basin Report (Mekong River Commission, 2019), 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 a 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 relevancy 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 2021, 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.** A List of water quality monitoring stations under the 2021 MRC WQMN

| Countries | STATID | Station Name | Names of Water Body | Monitoring Period | | Status[1] |
|---|---|---|---|---|---|---|
| | | | | 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 |

[1] "A" denotes an active station while "N' denotes a non-active or discontinued monitoring station

| Countries | STATID | Station Name | Names of Water Body | Monitoring Period | | Status[1] |
|---|---|---|---|---|---|---|
| | | | | Started | Ended | |
| Cambodia | H640110 | Kampong Toul | Prek Thnot | 7/15/95 | 12/14/03 | N |
| Lao PDR | H010500 | Houa Khong | Mekong | 8/17/04 | | A |
| 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 | H380104 | 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 |

| Countries | STATID | Station Name | Names of Water Body | Monitoring Period | | Status[1] |
|---|---|---|---|---|---|---|
| | | | | Started | Ended | |
| 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 |
| 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 |

| Countries | STATID | Station Name | Names of Water Body | Monitoring Period | | Status[1] |
|---|---|---|---|---|---|---|
| | | | | Started | Ended | |
| 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 |
| 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 |

In 2021, 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 1.2.2, 2.4.1.2.1, 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 which will be decentralised 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 in 2021

| 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 (ToR);
- 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 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 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 have as their purposes to provide decision supporting 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 key parameters were collaboratively adopted by the Member Countries to support the Member Countries maintain the good/acceptable water quality. For 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:***<br>▪ It can be observed as an oil film, sheen or discolouration.<br>▪ One can smell its odour, or<br>▪ It can be seen as oily deposits on the river bank 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 | 1000[(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 | 5000 | 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 - 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<br>Name | Symbol | Unit | Value | Analytical method[1] |
|---|---|---|---|---|---|
| 1 | Arsenic | Total As | mg/l | 0.01 | 3550-As/SM |
| 2 | Cadmium | Cd | mg/l | 0.005[2] | 3110-Cd/SM |
| 3 | Chromium Hexavelent | 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:***<br>• It can be observed as an oil film, sheen or discolouration.<br>• One can smell its odour, or<br>• It can be seen as oily deposits on the river bank 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 (ED). 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 2021 by assessing water quality monitoring data monitored by the WQMN laboratories in 2021 against the target values established by the TGWQ (Section 1.2.2);
- Exploratively analyse any spatial changes observed in the Mekong River water quality in 2021;
- Identify annual mean temporal changes observed for key water quality indicators at all 48 stations of the WQMN;
- Exploratively analyse and discuss any potential transboundary water quality issues observed in 2021;
- 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;
- Assess the operational effects of mainstream hydropower project (i.e., Don Sahong Hydropower Project) on water quality of the Mekong River; 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 (48) stations were monitored by the WQMN in 2021. 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 2021, 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 5 stations (3 in Cambodia and 2 in Viet Nam) and 6 stations, respectively. For the Bassac River, water quality was monitored at 5 stations with 3 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, 2 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 2021 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. For the purpose of this report, the names of these stations have been abbreviated as listed in Table 2.2 and their spatial locations are illustrated in Figure 2.1.

For consistency, the MCs have agreed to carry out the sampling and monitoring of water quality on a monthly basis between the 13th and 18th day of each month.

**Table 2.1.** A summary of 2021 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.** A list of the 48 water quality stations included in the 2021 Lower Mekong Water Quality Monitoring Report[2]

| Station[3] Abbr. | WQMN Station ID | Station Names | River Names | 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 |

[2] Stations are arranged in acordance with latitude descendent order.
[3] For the purposes of graphical illustration and reporting, the names of the 48 stations have been abbreviated. This table serves as an abbreviation defintion section of the 48 stations.

| Station[3] Abbr. | WQMN Station ID | Station Names | River Names | Country | Latitude | Longitude |
|---|---|---|---|---|---|---|
| CKT | H033403 | Koh Thom | Bassac River | Cambodia | 11.1054 | 105.0678 |
| 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 |

| | |
|---|---|
| (shaded) | Denotes mainstream stations |
| (unshaded) | Denotes other tributary stations including those located in the Bassac, 3S, and Tonle Sap Basins |


**Figure 2.1.** Spatial distribution of the 48 primary water quality stations monitored by the WQMN in 2021

## 2.2 Sampling techniques

In an effort to standardise the sampling techniques, in 2021 MRC continued to work with the designated WQMN Laboratories of the MCs to identify appropriate sampling techniques for collecting water samples. Through consultations, it was agreed that in 2021 water quality sampling, preservation, transportation, and storage would be carried out in accordance with methods listed in the Technical Guidelines for the PWQ (TGWQ) (Section 1.2.2) which have been 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 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 Water Quality Monitoring Network 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 2021, 19 water quality parameters were measured by the MRC WQMN (Table 2.3). Of these parameters, 12 are considered as routine water quality parameters requiring to be measured for each monitoring month. The other seven - major anions and major cations - are required to 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[4] | 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 ($NO_{2-3}$) | 4500-$NO_{2-3}$/SM | Monthly |
| Faecal Coliform (FC) | 9221-Faecal Coliform group/SM | Monthly |
| Total Suspended Solid (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 2021 require the collation and validation of water quality collected at national level by the Member Countries. The successful validation of these national databases allowed possible the agglomeration of regional water quality database which facilitated basin-wide analysis of water quality status and trends. Figure 2.2 illustrate the approach used for water quality data analysis to support this regional water quality data assessment report. The figure highlights 4 key types of data analyses encompassing the assessment water quality status in 2021, the spatial of assessment of changes in 2021, 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 details in Sections 2.4.1 to 2.4.4, but are summarized as follows:

- The evaluation of the status of the Mekong River water quality as recorded in 2021 (Section 2.4.1), in comparison to MRC water quality thresholds as listed in Chapter 1

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

"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);

- Explorative 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;
- Assessment of temporal variation of key water quality indicators at all 48 stations monitored in 2021 using a variety proven statistical techniques, as discussed in Section 2.4.3 of this report; and
- Explorative analysis and discussion on the potential transboundary water quality issues among stations strategically established to detect the conditions of water quality entering and leaving national boundaries of the Member Countries (2.4.4).

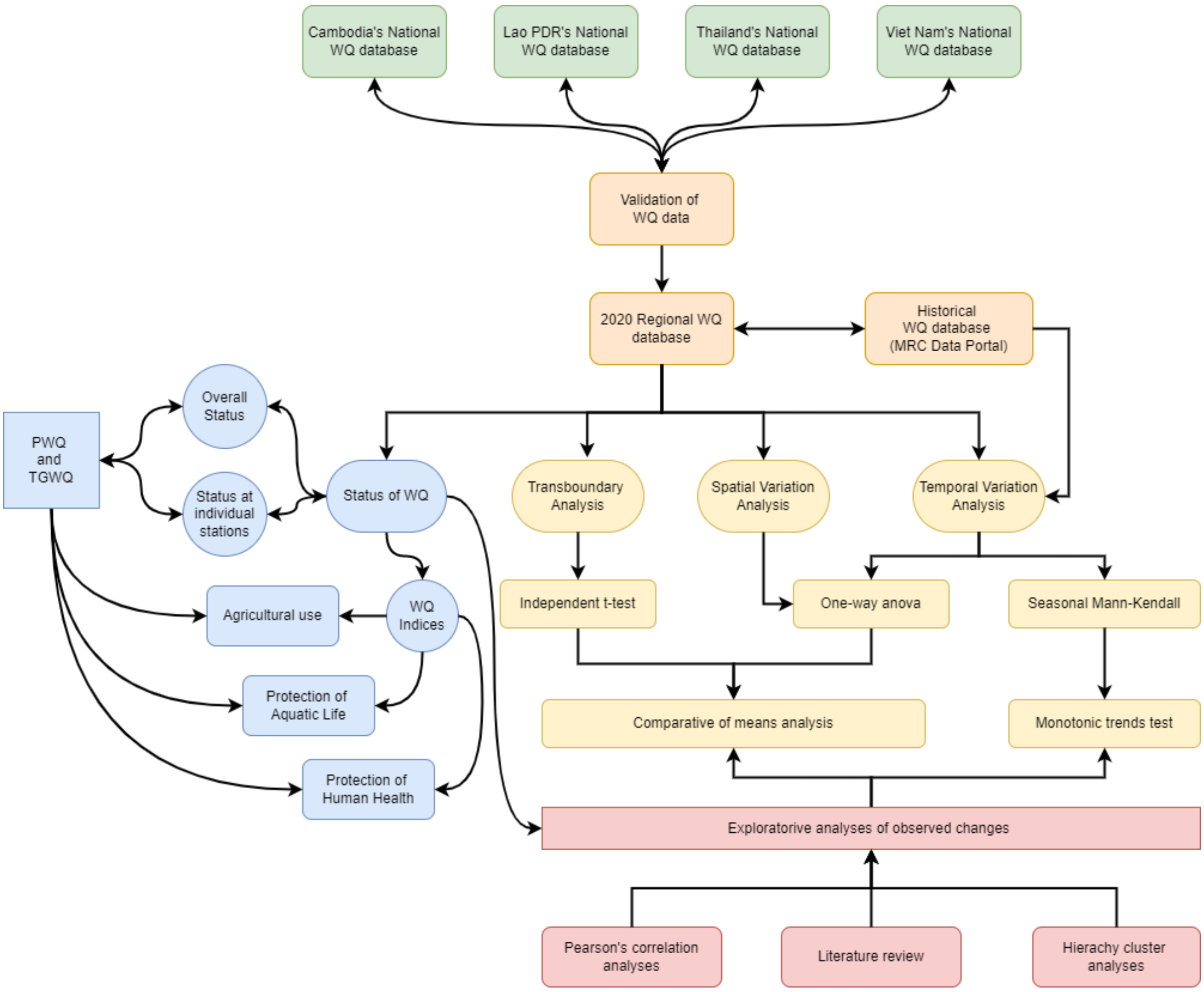



**Figure 2.2.** Conceptual illustration of the approaches use for the analyses of 2021 water quality data to support the identification of water quality status and spatiotemporal variation

## 2.4.1 Assessment of Water Quality Status

### 2.4.1.1 Descriptive Statistical Analysis

The overall status of the Mekong water quality in 2021 was examined by applying descriptive statistics such annual maximum, mean and minimum to summarise data series of key water quality parameters collected in 2021 along the Mekong River. Descriptive statistics are commonly used to analyse and compare various aspects of water quality data (Ai et al., 2015; Fisher & Marshall, 2009; Gu et al., 2019; He et al., 2009; Johnson et al., 2009), as they provide quick snapshots of data series that are generally large and not event distributed in nature (Fisher & Marshall, 2009; Lee, 2021). 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 noncompliance observed in any key water quality parameters were further characterised at an individual station level (Table 2.2) through additional descriptive statistical analysis assessment. These descriptive statistical concentrations were similarly 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 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 one of the key information to support the explorative 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 purposes were made 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 (WQIal);
- Water Quality Index for the Protection of Human Health (WQIhh); and
- Water Quality Index for Agricultural Use, which is divided into two categories (WQag):(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**. The index has been developed as an open-ended index which would allow more parameters to be added once data becomes 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 points 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 |
| $NO_{2-3}$ (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.

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

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

$$F_1 = \left( \frac{\#\, of\ failed\ parameters}{Total\ \#\, of\ parameters} \right)$$ 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**.

$$F_2 = \left( \frac{\#\, of\ failed\ tests}{Total\ \#\, of\ tests} \right)$$ 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**.

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

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

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

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

$$excursion = \left( \frac{failed\ test\ value}{guideline\ value} \right) - 1$$ 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 |
| $NO_{2\text{-}3}$ (mg/L) | 5 |
| COD (mg/L) | 5 |
| BOD[5] (mg/L) | 4 |

[5] 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.

**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, focusing 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 (electrical conductivity). The electrical conductivity 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[6] | | |
|---|---|---|---|---|
| | | None (A) | Some (B) | Severe (C) |
| **Electrical Conductivity** | | | | |
| General Irrigation | mS/m | <70 | 70-300 | >300 |
| Paddy Rice | mS/m | <200 | 200-480 | >480 |

### 2.4.2 Assessment of Spatial Variations

For the purpose of this report, two (2) distinct groups of spatial variation assessments were carried for stations located in the Mekong River mainstream and for those located in tributaries of the Mekong River including the Bassac River. As listed in Table 2.2, water quality monitoring under the WQMN was carried out at 17 mainstream stations, 5 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.

[6] None = 100% yield; Some = 50-90% yield; Severe = <50% yield

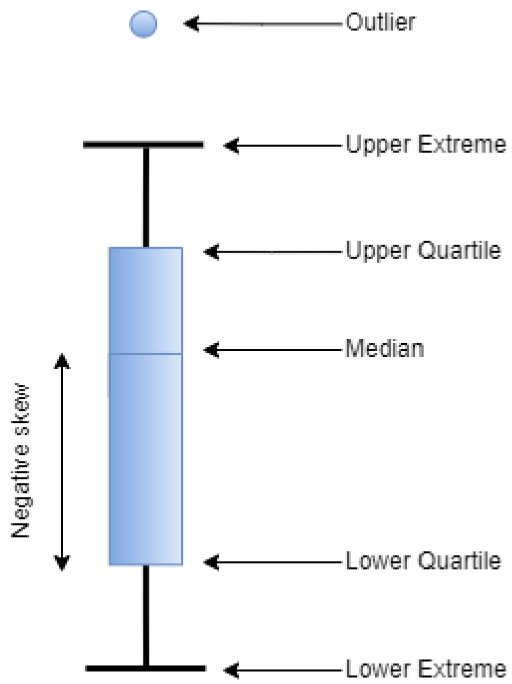



**Figure 2.3.** Information visualized by box-and-whisker plot

Graphically, the box-and-whisker plot (DuToit et al., 2012; Thompson, 1992) was used to visualize the distribution of 2021 water quality data for key parameters. While water quality data can be graphically illustrated in multiple different ways by box-and-whisker plot, the method is non-parameter statistical in nature and often has been used to support the analysis of non-normal distribute data, such as environmental monitoring data including water quality data, which highly is highly susceptible to the influences of seasonality and surrounding natural and anthropogenic factors (Larsen, 1985; Ly et al., 2020; Thirumalai et al., 2017). Using 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, 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 (Statistic Canada, 2021). Additionally, 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 & Gordon, 2009). For 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 box-and-whisker plot for spatial variation assessment of the 2021 water quality data along the 17 mainstream stations was support by the analyses of mean differences among the mainstream stations using one-way analysis of variance (one-way anova) (Heiberger & Neuwirth, 2009; Kim, 2017; Ross & Willson, 2017). This is because while the box-and-whisker plot may visually indicate spatial water quality variations among the stations monitored in 2021, 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 & Willson, 2017). Specifically, for the spatial assessment of water quality in this regional report, 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,

$\mu_1$ represents the mean concentration of station 1 (e.g., Houa Khong Station (LHK)),

$\mu_2$ represents the mean concentration of station 2 (e.g., Chiang Sean Station (TCS)),

$\mu_3$ represents the mean concentration of station 3 (e.g., Luang Prabang Station (LLP)), and so on, and

$\mu_n$ represents the mean concentration of station n, or for the purpose of this regional report – station 17 (e.g. My Tho Station).

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

Pearson's correlation analyses (Franzese & Iuliano, 2019) were performed to establish relationships between these parameters and to help explained 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.)[7] 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 (Benesty et al., 2009), as follows:

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

[7] As example, [pH]:[NO32] denotes a ratio of pH dataset to that of NO32.

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.

Aside from 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 past regional water quality data assessment report, the 2021 Regional Water Quality Data Assessment Report assess temporal variations at 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 record of water quality data was used for temporal assessment, covering period between 1985 to 2021 for many stations. Similar to the assessment of spatial variations (Section 2.4.2), a combination of graphical visualizations and statistical analyses were 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 seasonal Mann-Kendall test (Hirsch et al., 1982; Ly et al., 2020). Known as a non-parametric statistical method, seasonal Mann-Kendall test have been well utilised 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 et al., 2020). Proposed by Hirsch et al. (1982) as a seasonal modification to Mann-Kendall test (Al-Mashagbah & Al-Farajat, 2013), seasonal Mann-Kendall test the follow null and alternative hypotheses:

> $H_0$ = 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 compute $Z_{SK}$ 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' is the seasonal statistic of Mann-Kendall test and is the sum of the signs of difference between all combinations of observations while the VAR(S') is its variance. Hirsch et al. (1982) provides a detailed step-by-step of how these statistics can be calculated. For the purpose of 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. For this regional report, the seasonal Mann-Kendall test was carried out using an open source statistical software R Studio (RStudio, 2022).

To explain the observed statistically significant changes in both mean annual concentration (one-way anova) and monotonic trend (season Mann-Kendall test), similar explorative 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 literatures and/or research journals.

### 2.4.4 Exploration of Potential Transboundary Water Quality issues

The Mekong River Commission (2018), in its Technical Paper No. 19, identified five main transboundary areas along the Mekong River for assessing transboundary water quality in the Mekong and Bassac Rivers. These are:

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** — no water quality station exists in this part of the river since it is remote and sparsely populated.
3. **Thailand/Lao PDR** — a number of monitoring stations exist 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 as 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) 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 as transboundary stations, due to their proximity to the Cambodian/Vietnamese border.

6. **Viet Nam/Cambodia** – in 2021, the MRC WQMN monitored water quality of the 3S (Se Kong, Se San and Srepork Rivers) River System at 6 locations. These include 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 6 stations, Pleicu (VPC) and Phum Pi (CPH) can be considered transboundary stations due to their proximity to their proximity to the national boundary and one another. Therefore, this report has included these two stations when exploring potential transboundary water quality issues.

In exploring potential transboundary water quality issues among the identified transboundary stations, this 2021 water quality report utilizes both graphical visualization and statistical analysis to exploratively 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 box-and-whisker plot (Section 2.4.2 and Figure 2.3).

Statistically, two sample t-test (Fu & Wang, 2012; Gerald, 2018; von Sperling et al., 2021; Wilcox, 1990) was applied to determine whether there is a statistically significant difference between the mean concentrations of key water quality parameters of the two transboundary stations. In statistic and data science, t-test allow possible the comparison between 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 for this 2021 regional report, the two sample t-test was used to test whether a null hypothesis (H0) - in that 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 (HA) would be accepted (Equation 2.14).

$$H_0: \mu_1 = \mu_2 \qquad \text{Equation 2.13}$$

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

Where, µ1 and µ2 denote the average concentrations of a water quality parameter at station 1 and station 2, respectively. For this report, the sample t-test analysis was carried 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 literatures 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

Recognising 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 laboratory 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, while not being 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, having a sampling plan with clear sampling objectives and ensure 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 ion balance test; and
- Archive raw data and any important pieces of information relating to the results of the analysis in order to make it possible to trace all data and reconfirm the results of the analysis.

# 3. RESULTS

## 3.1 STATUS OF THE MEKONG WATER QUALITY IN 2021

In 2021, 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 3,027 data points for the 17 stations located in the Mekong mainstream; 972 data points for the 5 Bassac River stations; and 4,671 data points for the 26 tributary stations. The 2021 water quality status were assessed separately for mainstream and tributaries stations against the objectives of the MRC PWQ (Section 1.2.2) to ascertain whether water quality was still of "good/acceptable" conditions. Specifically, data of key water quality parameters was 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 analyses (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) and tributaries (Table 3.2 and Annex B). 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 quality of the river is still of "good/acceptable" quality compared to the established target values (Fu & Wang, 2012; von Sperling et al., 2021). The status of water quality in the Mekong mainstream and its tributaries in 2021 are discussed separately in Sections 3.1.1 to 3.1.2, below.

### 3.1.1 Mekong Water Quality in 2021

Results of descriptive statistical analyses of water quality data from 17 Mekong mainstream stations (Section 2.1 and Table 2.2) reveal that water quality of the Mekong River in 2021 was overall of moderately good quality with exceedance of WQGH and WQGA detected for six (6) water quality parameters (Table 3.1), including pH, electrical conductivity (EC), dissolved oxygen (DO), chemical oxygen demands (COD), biological oxygen demand (BOD), and faecal coliform (FC). Of the remaining 5 parameters (TSS, $NO_{3-2}$, NH4, TOTN, and TOTP) used as proxies for water quality in this report, data of one (1) parameter ($NO_{3-2}$) with established target value was well within its target values of WQGH (at all 17 stations) (Table 3.1).

Of the six (6) water quality parameters with one or more data points exceeding their respective target values of WQGH and WQGA, electrical conductivity (EC) values were found to be 100% outside of the recommended target range of 70 – 150 mS/m of the WQGH. Of these values in 2021, two (2) data points (approximately 1% of all EC data) were recorded to exceed 150 mS/m, with the highest EC value of 194.5 mS/m recorded at My Tho (VMT) station in April 2021 (Annex A). Being the final monitoring station in the Mekong River mainstream before the river discharges into the East Sea, My Tho has in the past recorded elevated EC levels due to saltwater intrusion. In 2021, about 17% of EC data recorded at VMT was found to be greater than 150 mS/m. This proportion of exceedance was found to be smaller when compared to the 33.3% exceedance in 2020.

On the contrary, approximately 99% of EC data recorded in 2021 were found to be less than 70 mS/m – the lower limit of the EC target values of WQGH (Chapter 1), with the lowest EC concentration of 10.80 mS/m being recorded at Savannkhet (LSV) station in December 2021 (Annex A). Overall, the EC levels in the Mekong mainstream were recorded to be highest during the dry season months with the average dry season concentration of 27.96 mS/m compared to 21.86 mS/m recorded during the wet season months. The difference was found to be statistically significant with 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 et al., 2022) of the Mekong River.

Aside from electrical conductivity, water quality of the Mekong River was found to be significantly impaired by elevated levels of faecal coliform (FC) with concentrations recorded in 2021 ranged from 9 to 43,000 MPN/100mL. Similar to levels recorded in 2020, the most prevalent FC impairments were recorded at Kampong Cham (CKC) and Chrouy Changvar (CCC) stations with all concentrations exceeded the target value of WQGH (1,000 MPN/100mL). At these two stations, concentrations for FC were recorded to range from 2,200 to 28,000 MPN/100mL. In 2021, the maximum FC concentration of 43,000 MPN/100mL was recorded at My Thuan (VMH) station in January 2021, whereas the minimum concentration of 9 MPN/100mL was recorded at My Tho (VMT) in May 2021. Despite the timing of the recorded maximum and minimum concentrations, FC levels in the Mekong mainstream were generally recorded to be highest during wet season months when increased surface runoff occurred due to the intense monsoon rainfall (Mekong River Commission, 2019). On average, the wet season faecal coliform concentration was estimated to be about 3,700 MPN/100mL at all mainstream stations (Table 3.1). In comparison, the average dry season faecal coliform concentration for the same mainstream stations was estimated to be 2,200 MPN/100mL (Table 3.1). The difference was found to be statistically significant by the normalized two sample t-test with p-value of less than 0.01. Faecal coliform impairment of the Mekong River water quality is expected given the current sanitation situations in the LMB, with open defecation rate remained high among rural population of the MRC Member Countries, at 80% and 24%, respectively in Cambodia and Lao PDR (UNICEF Cambodia, 2019; UNICEF Lao PDR, 2019).

Outside of EC and FC, exceedance of their respective target values were also recorded for COD and BOD. In 2021, concentrations for COD and BOD were recorded to ranged from 0.08 mg/L to 6.72 mg/L and 0 mg/L to 4.33 mg/L, respectively. For COD, the average concentration was estimated to be 2.38 mg/L (well below the target value of WQGH of 5 mg/L), with the maximum concentration recorded at Khong Chiam (TKC) in October 2021 while the minimum concentration recorded at Houa Khong (LHK) in August 2021. For BOD, the average concentration was estimated to be 1.26 mg/L, a value that is well below the target values of both the WQGH (4 mg/L) and WQGA (3 mg/L). In 2021, the maximum concentration of BOD was recorded at VMT in March 2021. Compared to the levels recorded in 2020, water quality of the Mekong River mainstream in relation to COD worsen slightly in 2021 with about 6% of concentrations exceeded the target value of WQGH (5mg/L). In comparison, only 3.5% of

COD concentrations exceeded the same target value in 2020. Conversely, instream BOD levels improved slightly in 2021 with only 1% of BOD concentration exceeded the target value of WQGH (4 mg/L) comparing to the 5.3% estimated in 2020.

Water quality impairment of the Mekong mainstream in relation to dissolved oxygen (DO) in 2021 was found to be moderate with 3.7 and 19.1% of DO concentrations fell below the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively. These proportions decreased slightly when compared to those recorded in 2020. In 2020, the proportions of DO concentrations fell below the target values of WQGA and WQGH were estimated at 8.6 and 23.2%, respectively. In 2021, lowest DO concentration of 4.03 mg/L was recorded at My Tho (VMT) in May. Along with VMT, My Thuan (VMH) and Tan Chau (VTC) were additional station recorded DO levels of less than the target value of WQGA (5 mg/L) during at least one monitoring occasion. At these three (3) Viet Nam's Delta stations (VMT, VMH and VTC), 94% of DO data were measured to be lower than the target value of WQGH (6 mg/L). DO monitoring at these locations may needed to be carried out at a more frequent period to capture a more near real-time profile of dissolved oxygen and facilitate the identification of potential causes and effects of low DO levels.

Addition to already discussed five (5) parameters, slight water quality impairment in relation to pH levels was also recorded in 2021, with the minimum pH value measured at 5.94. This pH value was recorded at VMT in December 2021 and represents the lone pH value to either exceed or fell below the recommended target ranges of pH (6 – 9) for both WQGH and WQGA. Outside of this minimum value, the average pH concentration of the Mekong River continued to be well within the recommended target values for the protections of human health (WQGH) and aquatic life (WQGA) (Table 3.1).

**Table 3.1.** Status of Mekong River water quality data as monitored in 2021 and compared to historical record (yellow 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/100mL) | BOD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TGWQ | **Chapter 1 (WQGH)** | | 6 – 9 | - | 70 - 150 | 5 | - | - | - | ≥ 6 | 5 | 1000 | 4 |
| | **Chapter 2 (WQGA)** | | 6 – 9 | - | - | 5 | - | - | - | 5 | - | | 3 |
| 2021 | Dry Season | Mean | 7.52 | 21.79 | 27.96 | 0.23 | 0.05 | 0.49 | 0.05 | 7.05 | 2.35 | 2,233.80 | 1.28 |
| | Wet Season | Mean | 7.44 | 84.06 | 21.86 | 0.26 | 0.07 | 0.53 | 0.07 | 6.70 | 2.41 | 3,705.00 | 1.25 |
| | Total | Max | 8.46 | 370.58 | 194.50 | 1.03 | 0.34 | 1.97 | 0.25 | 9.63 | 6.72 | 43,000.00 | 4.33 |
| | | Mean | 7.48 | 51.93 | 25.01 | 0.25 | 0.06 | 0.51 | 0.06 | 6.88 | 2.38 | 2,906.67 | 1.26 |
| | | Min | 5.94 | 2.85 | 10.80 | 0.01 | 0.00 | 0.07 | 0.00 | 4.03 | 0.08 | 9.00 | 0.00 |
| | | Std. Deviation | 0.39 | 55.93 | 18.49 | 0.20 | 0.06 | 0.39 | 0.04 | 0.99 | 1.55 | 6239.20 | 0.88 |
| Historical | Total | Max | 9.94 | 5716.00 | 841.00 | 1.42 | 2.99 | 4.89 | 2.20 | 13.85 | 65.00 | 24,0000.00 | 5.44 |
| | | Mean | 7.48 | 137.96 | 21.12 | 0.25 | 0.05 | 0.59 | 0.10 | 7.18 | 2.26 | 7,249.64 | 1.15 |
| | | Min | 3.78 | 0.10 | 1.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Std. Deviation | 0.50 | 244.30 | 29.73 | 0.18 | 0.10 | 0.40 | 0.12 | 1.10 | 1.92 | 19,758.35 | 0.96 |

### 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 2021. For the purposes of this report, tributaries of the Mekong River are grouped as follows:

- The five (5) Bassac River stations as monitored by the designated laboratories of Cambodia and Viet Nam (Table 1.2) with results summarized and discussed in Table 3.2;
- Six (6) tributary stations as monitored by the designated national laboratory of Lao PDR (Table 1.2) with results summarized in Table 3.2;
- Five (5) tributary stations as monitored by the designated national laboratory of Thailand (Table 1.2) with results summarized in Table 3.2;
- Five (5) tributary stations located in the 3S (Se San, Sre Pok and Se Kong) River System as monitored by the designated national laboratories of Cambodia and Viet Nam (Table 1.2) with results summarized in Table 3.2;
- Six (6) tributary stations located in the Tonle Sap River System, including those located in the Tonle Sap Lake, as monitored by the designated laboratory of Cambodia (Table 1.2) with results summarized in Table 3.2; and
- Viet Nam's Delta three (3) canal stations as monitored by the designated laboratories of Viet Nam (Table 1.2) with results summarized in Table 3.2.

In 2021, water quality at these groups of tributaries was largely in line with water quality condition of Mekong, with five (5) water quality parameters recorded to either exceed or fell below the target values of the WQGH and/or WQGA. Of significant note, EC levels were largely lower than the lower limit of the WQGH (70 – 150 mS/m), with the exception of levels measured at Houay Mak Hiao (LHM) and Ubon (TUB). At LHM (a tributary station in Lao PDR), EC concentrations ranged between 37.1 to 124.2 mS/m (Table 3.2) with the maximum EC value being the second highest among 48 stations of the WQMN, outside of those located in the Mekong Delta (Section 3.1.1). In 2021, 67% of the EC data at LHM was recorded to be higher than the lower limit of the WQGH (70 mS/m). At TUB (a tributary station in Thailand), the maximum EC value of 143.2 mS/m in June 2021 and represented the only EC concentration at this station to be recorded at levels higher than 70 mS/m – the 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 2021, the maximum EC value of 28.7 mS/m was recorded at Chau Doc (VCD) in April 2021 while its minimum value of 10.1 mS/m was recorded at Can Tho (VCT) in October 2021.

For FC, concentrations recorded in the Mekong tributary stations ranged from 4 to 240,000 MPN/100mL with the maximum FC concentration of 240,000 MPN/100mL recorded at VCD in October 2021. At VCD, FC concentrations were highly variable with values ranged from 43 to 240,000 MPN/100mL. Despite recorded highest FC concentration among the 48 mainstream and tributary stations, only 25% of FC concentrations at VCD exceeded the target value of WQGH (1,000 MPN/100mL). In comparison, 100% of FC concentrations at Phnom Penh Port (CPP) station exceeded the same target value in 2021. At CPP, FC concentrations were less variable with values ranged from 3,900 to 32,000 MPN/100mL and an average concentration of about 15,000 MPN/100mL. Tributary stations located in Lao PDR and Thailand also recorded sporadic exceedance of FC concentrations with maximum concentrations of 1,400 and 16,000 MPN/100mL recorded among the groups of tributary stations in Lao PDR and Thailand, respectively. Among tributary stations located in Lao PDR and Thailand, FC's proportion of exceedance were estimated to be 1.4% and Thailand 15.2%, respectively.

For COD, the maximum concentration was recorded to be 13 mg/L at Chiang Rai (TCR) – a tributary station located in Thailand. At this station, about 58% of COD concentrations was recorded to exceed the target value of the WQGH (5 mg/L), resulting in an average COD concentration of 6.84 mg/L. Collectively, about 62% of COD concentrations recorded at the five (5) tributary stations located within Thailand's national boundary exceeded the target value of WQGH (5 mg/L) in 2021, with a combined average concentration of 5.71 mg/L. These figures represent a significant increase when compared to the 2020 figures where only 23.6% of COD concentrations exceeded the target value of WQGH. Aside from the exceedance recorded in Thailand's tributaries stations, exceedances of COD target value were also recorded in tributary stations located in Lao PDR (14.8%), 3S River System (1.4%), Tonle Sap Basin (20.8%), Bassac River (8.33%), and Viet Nam's Canal (19.4%).

Despite recorded high proportion of COD exceedance, Thailand's tributary stations did not record any BOD exceedance in 2021 with the average value of 1.4 mg/L – a value which is well below the target values of WQGH (4 mg/L) and WQGA (3 mg/L). Among the tributary stations, the maximum BOD concentration of 3.9 mg/L was recorded at Houay Mak Hiao (LHM) in January 2021. At LHM, approximately 33% of COD concentrations exceeded the target value of WQGA (3 mg/L), although no exceedance of WQGH target value was recorded. It should be noted that LHM continued to receive drainage water and runoff from Vientiane Capital with elevated levels likely resulted from the increased wastewater discharge due to increase urbanization and the reduction of natural buffer capacity of areas upstream of the monitoring station (Epprecht et al., 2018; Guédron et al., 2014; Okamoto et al., 2014). Aside from LHM, tributary stations located in the Bassac River also recorded exceedance of WQGA's target value of 3 mg/L. Specifically, a maximum BOD concentration of 3.4 mg/L was recorded at Chau Doc (VCD) in November 2021. Collectively, 15% of BOD concentrations measured at the Bassac River's tributary stations exceeded the target value of WQGA (3 mg/L), although no exceedance of the target value of WQGH (4 mg/L) was recorded in 2021.

As shown in Table 3.2, among the tributary stations of the Mekong River, the lowest DO concentration of 3.1 mg/L was recorded at Houay Mak Hiao (LHM) in July 2021. At LHM, 56% and 89% of DO concentrations were recorded to be lower than WQGA (5 mg/L) and WQGH (6 mg/L), respectively. Aside from LHM, no other tributary station in Lao PDR recorded DO concentration lower than 6 mg/L (a target value of WQGH). On the Western Side of the Mekong River, DO concentrations of tributary stations located within Thailand's national boundary ranged from 3.55 to 10.0 mg/L, with the minimum DO concentration of 3.55 mg/L recorded at Mun (TMK) in October 2021. Collectively, the 46.6 and 22.4 % of DO concentrations measured at the five (5) tributary stations of Thailand felt below the target values of WQGH (6 mg/L) and WQGA (5 mg/L), respectively.

With concentration ranged from 4.2 to 5.8 mg/L, DO levels of the three (3) Viet Nam's Delta canal station failed to meet the target value of WQGH (6 mg/L). Furthermore, about 33.3 % of the DO concentrations were measured to be lower than the target value of WQGA (5 mg/L), with the lowest concentration of 4.2 mg/L measured at Tu Thuong (VTT) in January 2021. While water quality of Mekong River tributaries continued to be impaired for human health with respected to DO, water quality for the protection of aquatic life improved slightly when compared to 2020 when 66.7% of DO concentrations were recorded to be lower than the target value of WQGA (5 mg/L).

For the Bassac River, approximately 18.3 and 40% of DO concentrations were measured to exceed the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively. For comparison, about 15.8 and 40.4% of the Bassac DO concentration were lower than the same target values in 2020. Of the five (5) Bassac monitoring stations, 100% of DO concentrations at VCD and VCT were lower than the target value of WQGH (6 mg/L), of which 46% was below 5 mg/L. The lowest DO concentration of 4.4 mg/L was recorded at VCT in May 2021.

**Table 3.2.** Water quality status of key tributaries of the Mekong River in 2021 (yellow colour marks non-compliance with WQGH or WQGA)

| 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/100mL) | 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 | 8.7 | 258.5 | 124.2 | 2.1 | 0.7 | 5.8 | 0.4 | 9.8 | 7.1 | 1400.0 | 3.9 |
| | Mean | 7.4 | 49.2 | 26.6 | 0.3 | 0.0 | 0.8 | 0.1 | 6.7 | 2.8 | 188.5 | 1.7 |
| | Min | 6.3 | 3.7 | 4.2 | 0.0 | 0.0 | 0.1 | 0.0 | 3.1 | 0.1 | 18.0 | 0.5 |
| | Std. Deviation | 0.5 | 65.6 | 28.5 | 0.5 | 0.1 | 1.1 | 0.1 | 1.2 | 1.8 | 244.1 | 1.1 |
| Thailand's Tributaries | Max | 8.6 | 636.6 | 143.2 | 0.6 | 0.2 | 1.0 | 0.3 | 10.0 | 13.0 | 16000.0 | 1.4 |
| | Mean | 7.3 | 42.9 | 25.7 | 0.2 | 0.1 | 0.5 | 0.1 | 5.9 | 5.7 | 768.0 | 0.8 |
| | Min | 6.5 | 0.3 | 8.0 | 0.0 | 0.0 | 0.2 | 0.0 | 3.6 | 1.7 | 18.0 | 0.2 |
| | Std. Deviation | 0.4 | 98.2 | 21.0 | 0.2 | 0.0 | 0.2 | 0.1 | 1.2 | 2.2 | 2301.6 | 0.3 |
| 3S River System | Max | 8.4 | 163.0 | 12.2 | 1.0 | 0.3 | 1.2 | 0.5 | 8.5 | 5.2 | 43000.0 | 2.2 |
| | Mean | 7.4 | 37.8 | 6.8 | 0.2 | 0.1 | 0.4 | 0.1 | 6.9 | 2.3 | 3336.8 | 1.7 |
| | Min | 6.2 | 1.9 | 2.4 | 0.0 | 0.0 | 0.1 | 0.0 | 5.2 | 0.8 | 4.0 | 1.1 |
| | Std. Deviation | 0.5 | 37.5 | 1.7 | 0.2 | 0.1 | 0.3 | 0.1 | 0.9 | 1.1 | 11917.4 | 0.3 |
| Tonle Sap Basin | Max | 7.9 | 1584.0 | 27.6 | 0.7 | 0.4 | 0.8 | 0.9 | 7.8 | 7.6 | 32000.0 | 1.1 |
| | Mean | 7.4 | 173.1 | 15.2 | 0.1 | 0.1 | 0.3 | 0.2 | 6.8 | 3.7 | 15100.0 | 0.9 |
| | Min | 6.5 | 17.5 | 11.6 | 0.0 | 0.0 | 0.1 | 0.0 | 4.8 | 1.5 | 3900.0 | 0.7 |

| 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/100mL) | 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 | 0.3 | 283.0 | 3.0 | 0.1 | 0.1 | 0.1 | 0.2 | 0.6 | 1.6 | 9257.2 | 0.1 |
| Bassac River | Maximum | 8.2 | 185.4 | 28.7 | 1.2 | 0.4 | 3.1 | 0.3 | 7.8 | 7.5 | 240000.0 | 3.4 |
| | Mean | 7.4 | 48.9 | 19.0 | 0.3 | 0.1 | 0.7 | 0.1 | 6.3 | 3.5 | 13333.0 | 2.0 |
| | Minimum | 6.4 | 6.9 | 10.1 | 0.0 | 0.0 | 0.2 | 0.0 | 4.4 | 1.3 | 40.0 | 0.7 |
| | Std. Deviation | 0.3 | 39.3 | 4.8 | 0.3 | 0.1 | 0.5 | 0.1 | 1.1 | 1.3 | 34735.2 | 0.7 |
| Viet Nam's Canal | Max | 7.8 | 97.0 | 44.0 | 1.1 | 0.8 | 1.9 | 0.8 | 5.8 | 7.3 | 15000.0 | 2.8 |
| | Mean | 7.2 | 45.8 | 20.4 | 0.4 | 0.2 | 1.1 | 0.2 | 5.1 | 4.6 | 1677.5 | 2.0 |
| | Min | 6.5 | 15.0 | 5.7 | 0.1 | 0.0 | 0.5 | 0.0 | 4.2 | 3.4 | 43.0 | 1.2 |
| | Std. Deviation | 0.3 | 22.0 | 6.8 | 0.2 | 0.2 | 0.4 | 0.2 | 0.4 | 0.8 | 3136.8 | 0.4 |

## 3.2 CORRELATION OF KEY WATER QUALTY INDICATORS

The relationships between key water quality parameters monitored in 2021 have been established and shown in 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 statistically significant at 0.01 level, whereas the relationship between $NO_{3-2}$ and $NH_4N$ was also statistically significant at p-value of 0.05 level. Conversely, the negative relationship between $NO_{3-2}$ and DO was revealed to be statistically significant at 0.01 level. In other words, as EC, TOTN, COD, BOD, TOTP and/or NH4N levels increased so are the levels of $NO_{3-2}$. Conversely, the decreased in $NO_{3-2}$ levels are expected to accompany the increased DO levels. Table 3.3 also revealed that while there appear 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 (2-tailed).

**Table 3.3.** Relationships among key water quality parameters in the Mekong River as monitored by the WQMN from 1985 to 2021

| 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 indicators to indicators with statistically significant variations 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. Similar to 2020, TSS was the lone key water quality indicator (outside of the major cations and anions indicators)[8] not exhibiting statistically significant variation on a spatial scale in 2021, with ANOVA p-value of 0.90.

Of the ten (10) indicators exhibited statistically significant spatial variations, overall downward trends were detected for pH (Figure 3.1a) and DO (Figure 3.3a) with generally lowest pH and DO concentrations measured in the Mekong Delta region. In the upper part of the Mekong River mainstream, generally higher and more variable pH and DO levels were recorded in 2021. Specifically, the average pH and DO concentrations of the three uppermost stations (LHK, TCS, LLP) were 7.44 and 7.16 mg/L, respectively. In comparison, the average pH and DO concentrations of the three lowermost stations (VMT, VMH, VTC) were 7.27 and 5.20 mg/L, respectively. Variation of pH and DO levels have been attributed to both natural and anthropogenic processes (Michaud, 1991; Sheldon et al., 2019; USGS, 2019). Prolong exceedances against the target values of WQGH and WQGA could lead to severe water quality impairment, as pH of water are 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. This is because pH affects the solubility and availability of nutrients and heavy metals in water (Swenson & 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).

Likewise, prolong low DO level can reduce the ability of the Mekong River to support aquatic life (Michaud, 1991). In 2021, pH and DO levels were positively correlated to one another with Pearson's Correlation Coefficient of 0.265 and at a significant level of 0.01 (Table 3.3). This indicates that as pH levels decreased so do the DO levels, as spatially illustrated by Figure 3.1a and Figure 3.3a. Conversely, results of Pearson's correlation analysis (Table 3.3) reveal statistically significant negative relationships between pH and TOTP, COD and BOD, whereas DO was revealed to have statistically negative relationships with EC, $NO_{3-2}$, TOTP, COD, 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 found to be generally highest at the three (3) Viet Nam's Mekong Delta stations (VTC, VMH, and VMT). Correspondingly, 97.2% of the DO concentrations at these three stations were measured to be less than the target value of WQGH (6 mg/L) and may not be suitable for the protection of human health. With 19.4% of the DO concentrations measured at the same three (3) stations to be 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 inhabit the Viet Nam's Mekong Delta.

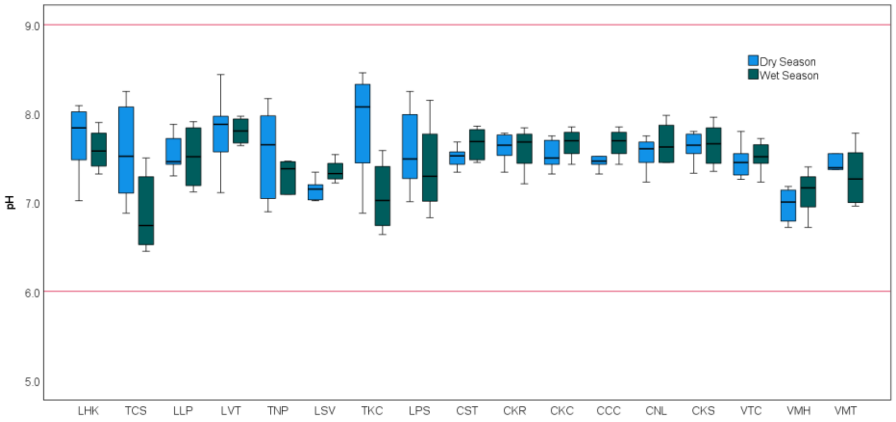
A combination of the elevated concentration levels of these water quality indicators and the reduced DO and pH levels could signify the increased pollution levels in Mekong Delta region due to human activities and densely urbanized areas (Mekong River Commission, 2019). Given that nutrients, COD and BOD levels were generally higher during the dry season

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

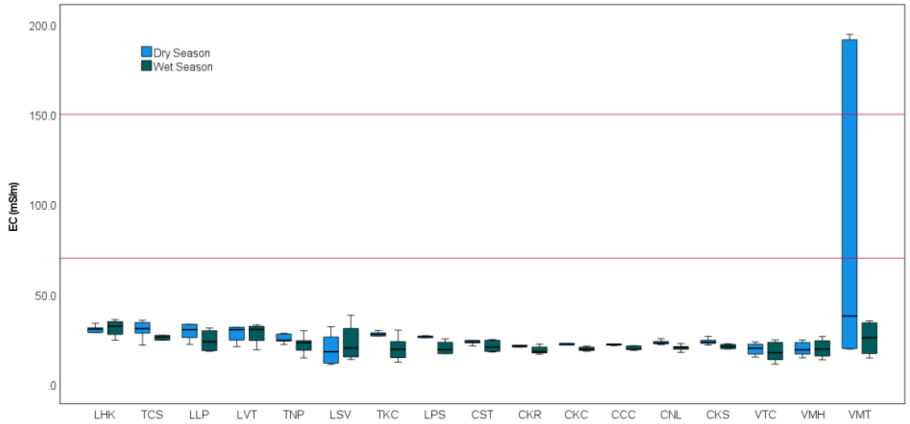
compared to the wet season at these stations, the causes of the increased instream pollution levels may be connected to direct wastewater discharge into the Mekong River, locally and to a lesser extent transboundary via instream transport of nutrients and biochemical oxygen demands pollutants.

Additionally, special attention should be given to the elevated EC levels measured 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 concentrations at VMT had historically been measured at levels greater than 500 mS/m, these elevated values were generally measured during the hightide. In 2021, EC measurements were carried out during low tide, when the Mekong River was flowing from inland to the East Sea. Nonetheless, EC concentrations were recorded to be higher than 190 mS/m at two occasions, exceeded both the WQGH upper target value of 150 mS/m, as well as the degree of consequence values for calculating Water Quality Index for Agricultural Use – General Irrigation (70 mS/m) (Table 2.8). Given that these elevated EC levels were measured during the dry season, the levels are of significant concerns and could potentially signify the increased effects of saltwater intrusion in combination of increasing climate variability (Ly et al., 2022; Reid et al., 2019) and reducing flow in the Mekong mainstream (Hecht et al., 2019; Trung et al., 2018). In light of the monitoring results at VMT, further investigate and monitor at a more frequent period should be carried out 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.

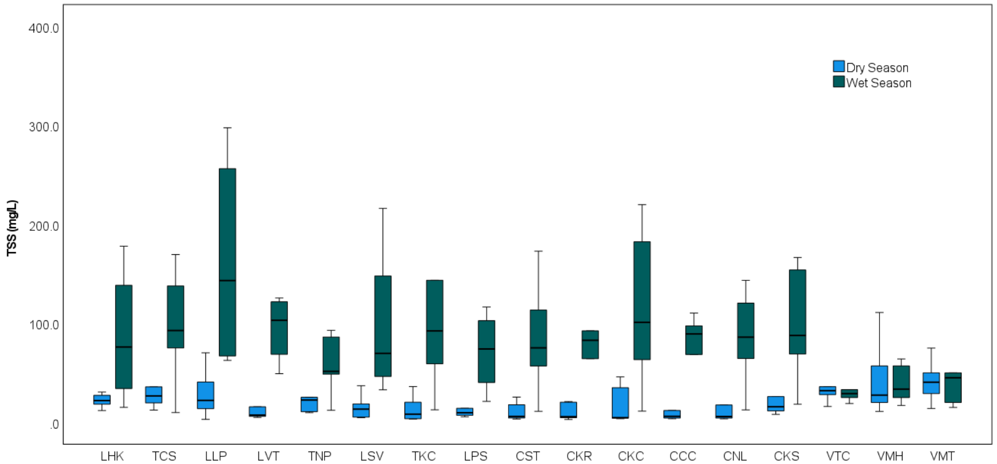
In 2021, faecal coliform (FC) was monitored at 13 stations along the mainstream where concentrations were highly variable and influenced by seasonality, as discussed in Section 3.1.1. Figure 3.3d depicts the spatial variations of FC along the Mekong River with elevated concentrations recorded in the middle and lower sections of the river. In the Lao PDR and Thailand's section of the river, 10% of FC concentrations were recorded to exceed the target value of WQGH (1000 MPN/100mL) whereas approximately 66% of FC concentration measured in Cambodia and Viet Nam's section of the river exceeded the same target value. Of special note, 100% of FC concentration recorded at the two Cambodia's stations (CKC and CCC) exceeded the same target value. With highest concentrations 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 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). Elevated faecal coliform (FC) levels should be considered when utilizing the Mekong River and its tributaries as portable water with the World Health Organization guidelines be strictly observed (WHO, 2011).




(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)

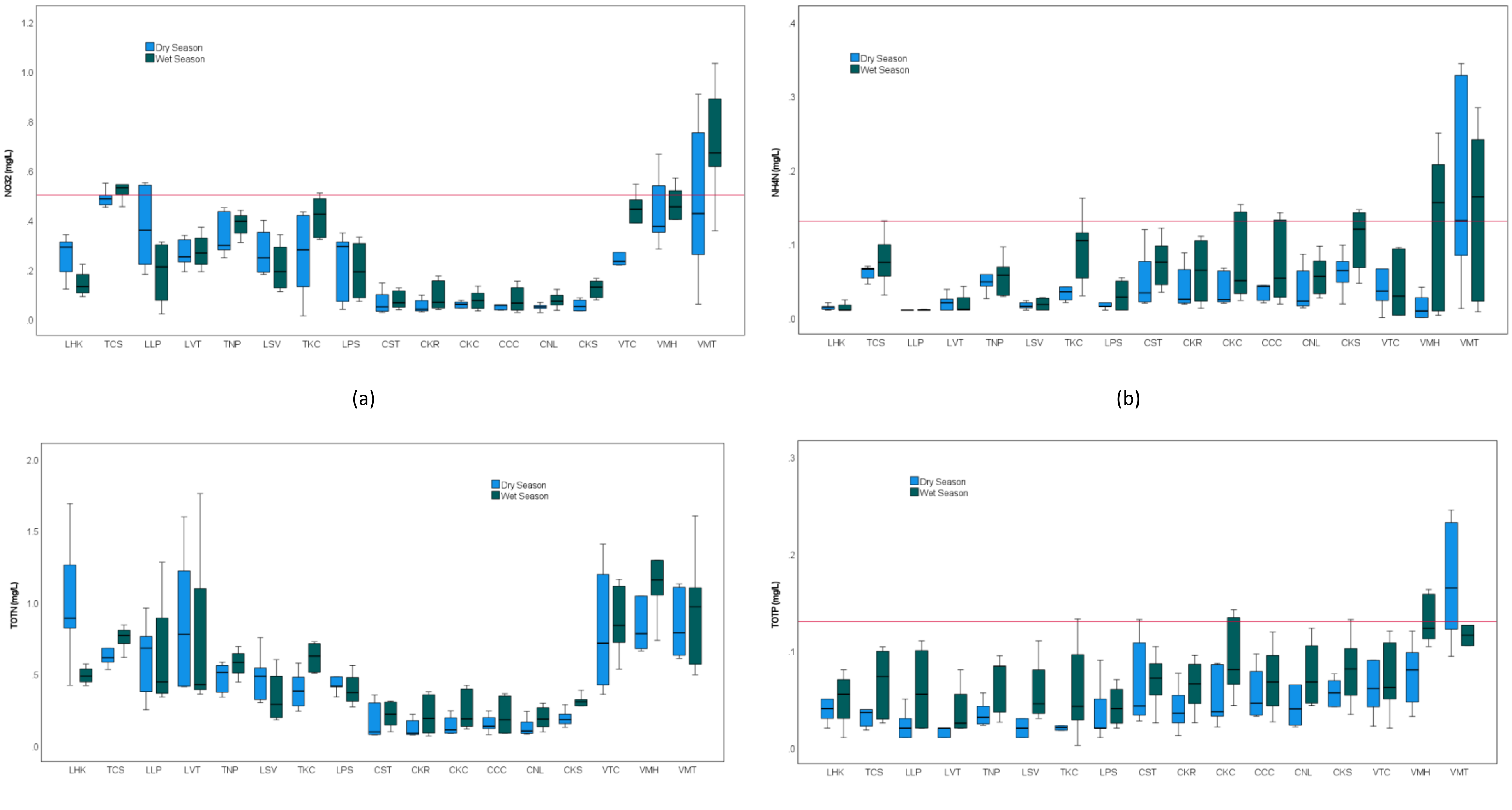
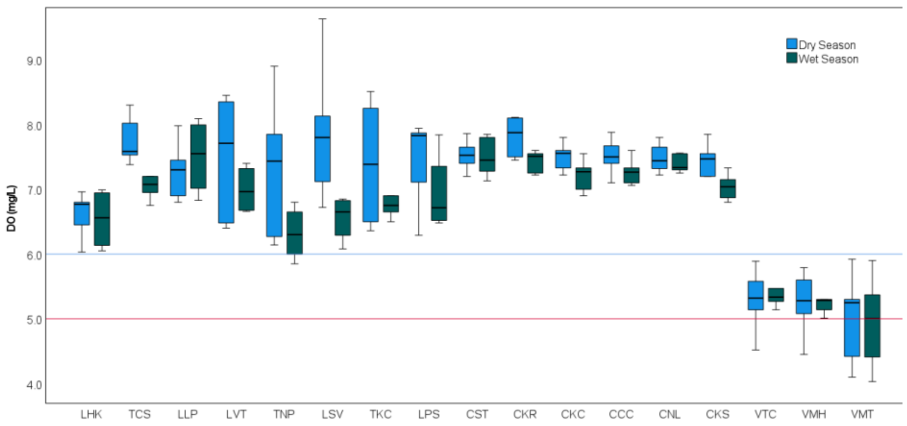
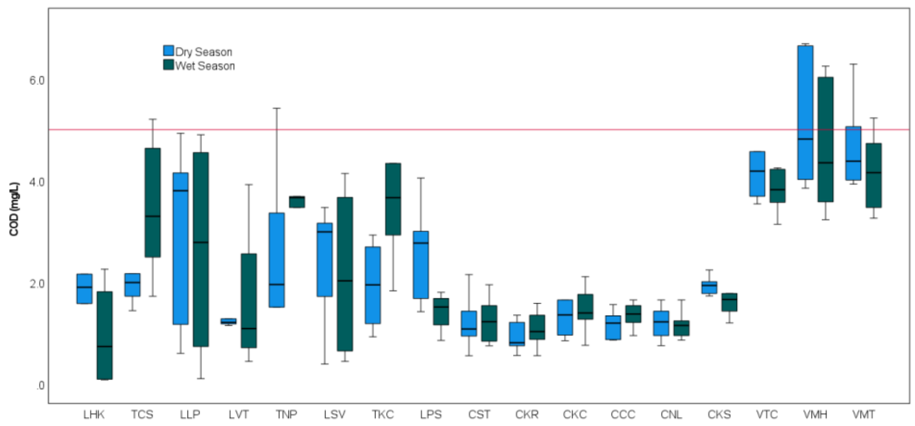


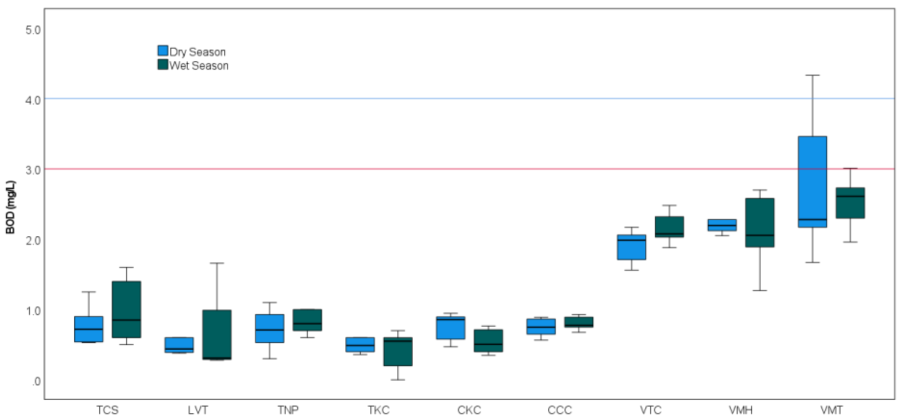

**Figure 3.2.** Seasonal spatial distribution of (a) $NO_{3-2}$, (b) $NH_4N$, (c) TOTN and (d) TOTP levels along the Mekong River from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)



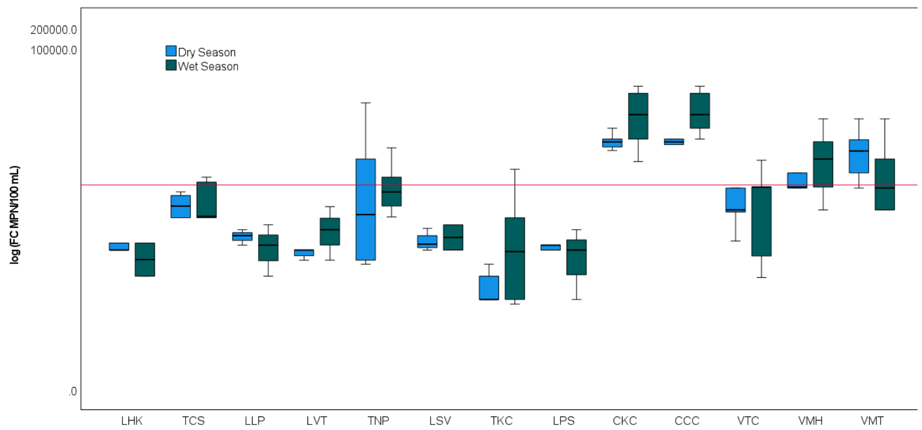

(a)




(b)




(c)




(d)

**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)[9]

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[9] 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 the purposes of spatial assessment and comparison, tributary stations are grouped into six (6) group based on their geographical and sub-basin locations. These six groups of tributaries include (Table 2.2):

- Lao PDR's tributary stations which comprise LBK, LBH, LHM, LSB, LBD and LSD;
- Thailand's tributary stations comprising of TCR, TBC, TNK, TMK, and TUB stations;
- Tributary stations located in the 3S River System including CSP, VPC, VBD, CAM, and CPH;
- Tributary stations located in the Tonle Sap Basin including 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 water quality indicators examined as part of this report, no significant spatial variation was detected in the levels of pH among the tributaries of the Mekong River in 2021 with all values fell within the target ranged of both WQGH and WQGA (Figure 3.4a). Other than EC levels at LHM, all EC values measured in 2021 in tributary station were well below 70 mS/m – the lower limit of the WQGH. At LHM, EC values measured in 2021 ranged from 37.1 mS/m to 124.2 mS/m with elevated level generally measured during the dry season indicating a potential of direct input of wastewater into Houay Mak Hiao (please refer to Section 3.1.2).

Water quality in term of TSS levels was highly variable with the largest TSS range measured at Phnom Krom (CPK) from 18.5 mg/L in November 2021 to 1,584.0 mg/L in March 2021. Given that the maximum value was recorded during the dry season (March 2021), instream TSS levels at Phnom Krom may have been periodically influenced by instream and/or bank activities, including inland water navigations and fishery activities (Ang & Oeurng, 2018; Ratha et al., 2016).

Since its inception, the WQMN has monitored instream nutrient levels through $NO_{3-2}$, $NH_4N$, TOTN, and TOTP. In 2021, instream nutrient levels varied among tributaries and stations, as can be seen in Figure 3.5. Instream $NO_{3-2}$ levels, which are known to be associated with point and nonpoint sources of urban and/or agricultural runoff (Howarth et al., 2002; Ly et al., 2020; Young et al., 1989), were slightly elevated at stations receiving runoff from densely populated and/or agriculture intensive areas including LHM, VPC, VBD, the two Viet Nam's Bassac stations (VCD, and VCT), and two Viet Nam's canal stations (VTB and VTH) (Figure 3.5a). Similar to those observed along the mainstream stations (Section 3.3.1.1), spatial variation of instream TOTN follow the same patterns of those $NO_{3-2}$, and further confirmed the significant positive correlation between $NO_{3-2}$ and TOTN (Section 3.2 and Table 3.3). With spatial variation somewhat different from those of TOTN, Figure 3.5b further confirms that $NH_4N$ is the less dominant nitrogen nutrients making up total nitrogen cycle in tributaries of the Mekong River when compared to $NO_{3-2}$ (Figure 3.5a). For $NH_4N$, instream levels were highest at the three Viet Nam's canal stations (VTB, VTH, and VTT) with the maximum $NH_4N$ concentration of the three stations reaching 0.845 mg/L in January 2021 (VTH). With concentration generally measured to be highest during the dry season (Please refer Section

3.1.2), elevated instream $NH_4N$ levels may have been influenced by the increased direct input of wastewater into the Mekong and its tributaries (Ratha et al., 2016) and the decreased capacity of the river to dilute these wastewater inputs (Prathumratana et al., 2008; Wilbers et al., 2014).

In 2021, total phosphorus concentrations were highly variable among tributary stations with levels appear to be highest and more variable at stations located in the Tonle Sap River and Viet Nam's canal system (Figure 3.5d). Of particular concern is the levels at Phnom Krom (CPK) which ranged from 0.09 mg/L (November and December 2021) to 0.94 mg/L (April 2021). At CPK, elevated levels were generally measured during the dry season with average monthly dry season concentration of 0.44 mg/L, compared to 0.33 mg/L of the average wet season monthly concentration. It is also interested to note that in 2021, 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 both natural process 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 (Liu et al., 2018). 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, increase in instream levels can cause water quality problems including accelerated algae blooms and reduced DO levels essential for aquatic fauna (USEPA, 2012c). Aside from CPK, 18 other tributary stations recorded TOTP concentrations exceeding the target value used for Water Quality Index for the Protection of Aquatic Life (0.13 mg/L) (Table 2.4). These exceedances are expected to affect the rating of water quality for the protection of aquatic life at these stations (to be discussed in Section 3.5.1).

In 2021, DO, COD and BOD levels fluctuated station to station and tributary to tributary. Spatially, DO exhibits opposite patterns of those recorded for COD and BOD (Figure 3.6a, b and c). In 2021, 10 and 16 tributary stations recorded DO concentrations below the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively. Of significant concerns, 89 and 100% of DO concentrations recorded at LMH were below the target values of WQGA and WQGH, respectively. Given reduced DO levels, it would be good to continue monitor water quality at LMH and investigate its impact on the Mekong mainstream through special monitoring of water quality of the Mekong River at location immediately downstream of Houay Mak Hiao confluence.

In addition to the reduced concentrations recorded at LMH, stations located in Viet Nam's national boundary also recorded lower DO concentrations than others. Specifically, 100% of DO concentrations recorded at the five stations located in Viet Nam's Mekong Delta (VCD, VCT, VTT, VTB, VTH) were lower than the target value of WQGH (6 mg/L), indicating that water quality at these stations may not be suitable for the protection of human health. At these same stations, 38.3 % of DO concentrations were recorded to be lower than the target value of WQGA (5 mg/L). Likewise, the two Viet Nam's Central Highland stations (VPL and VBD) also recorded about 96% of DO concentrations to be lower than the target value of WQGH (6 mg/L). However, it should be noted that all DO concentrations recorded at VPL and VBD were above the target value of WQGA (5 mg/L) indicating that water quality at these two stations was still suitable for the protection of aquatic life despite not being a suitable for the protection of human health.

Other stations with more than 20% of measured DO concentrations of less than 6 mg/L in 2021 include TBC (36.4%), TNK (54.6%), TUB (66.7%) and TMK (66.7%) in Thailand. Collectively, 22.4% of DO concentration data recorded at the five Thailand's tributary station were lower than the target value of WQGA (5 mg/L).

Spatially, similar patterns were observed for COD and BOD (Figure 3.6b and c, respectively). These patterns were direct opposite of that of DO (Figure 3.6a) where stations with reduced DO concentrations generally recorded elevated COD and BOD concentrations, including LHM where COD and BOD concentration ranged from 3.13 to 7.11 mg/L and 1.2 to 3.86 mg/L, respectively. Despite the reduced DO levels, COD and BOD concentrations of stations located in Viet Nam remained largely below their respective target values of WQGH and WQGA (Figure 3.6b and c), with the only exception being the noticeable elevated COD concentrations at VTH or Thong Binh station. At Thong Binh (VTH), COD concentrations were recorded to exceed the target value of WQGH (5 mg/L) on 33.3% monitoring occasions.

Faecal coliform levels were highest at stations located within Cambodia's national boundary including CPP, CTK and CKT. At these stations, FC concentrations ranged from 3,900 to 39,000 MPN/100mL. With the minimum FC concentration of 3,900 MPN/100mL, 100% of FC data monitored at these three stations exceeded the target value of WQGH (1,000 MPN/100mL). Aside from these three stations, all tributary stations located in Viet Nam's Mekong Delta recorded at least one FC value that exceeded the threshold value of WQGH (1000 MPN/100mL). In addition, TCR and LMH also recorded at least one FC concentration that exceeded the target value of WQGH (Figure 3.6d).

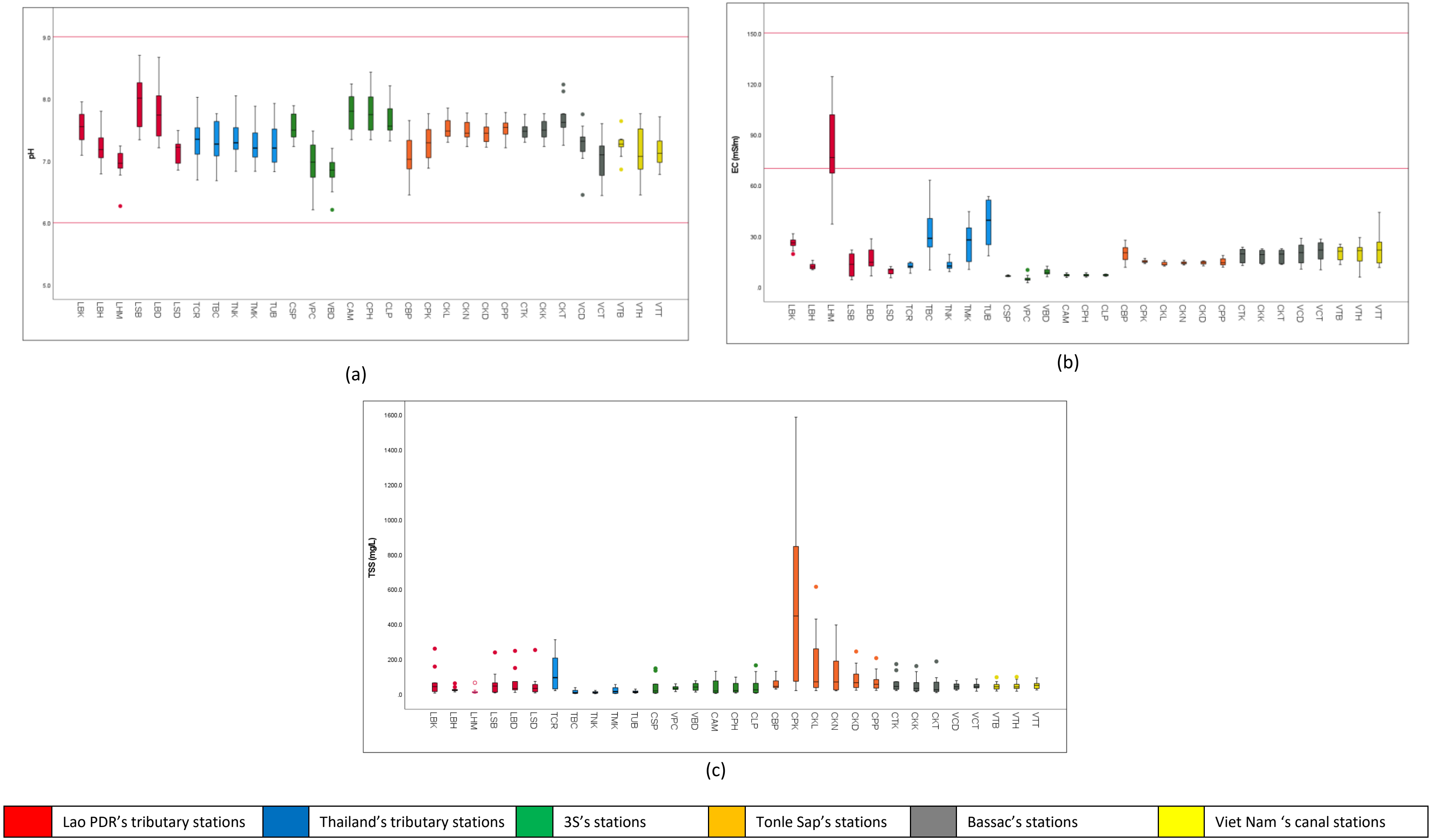
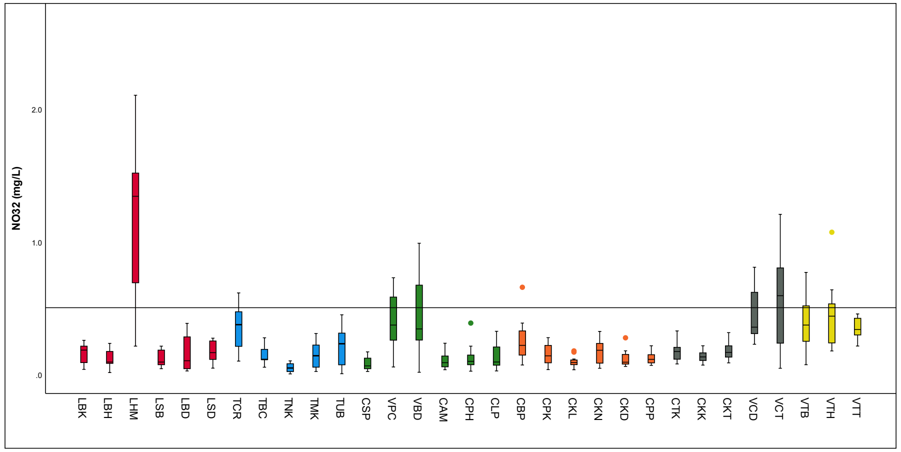



**Figure 3.4.** Spatial distribution of (a) pH, (b) EC and (c) TSS levels at key tributaries of the Mekong River in 2021

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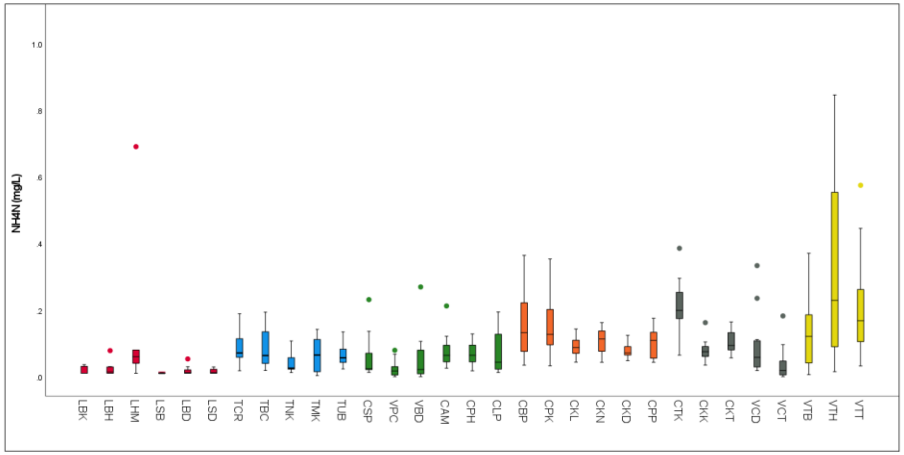


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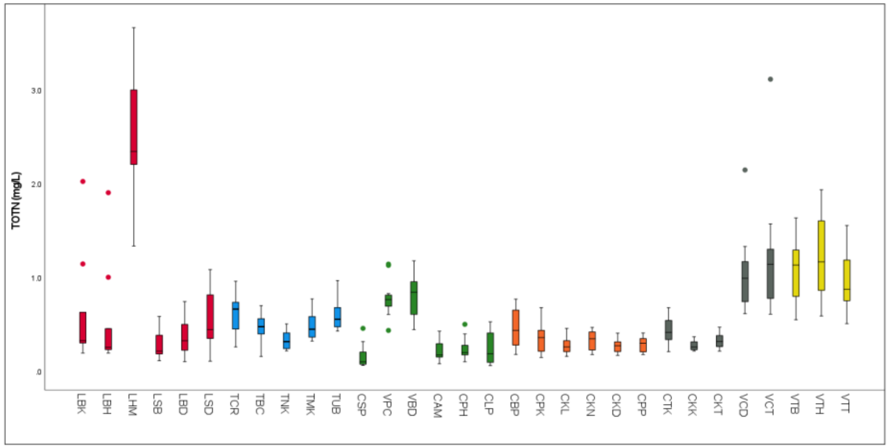


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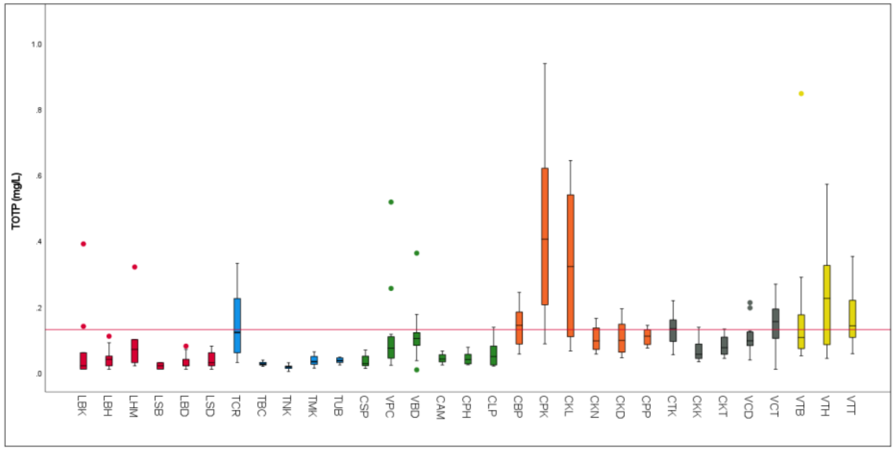



(d)

| | | | | | |
|---|---|---|---|---|---|
| Lao PDR's tributary stations | Thailand's tributary stations | 3S's stations | Tonle Sap's stations | Bassac's stations | Viet Nam 's canal stations |

**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 in 2021

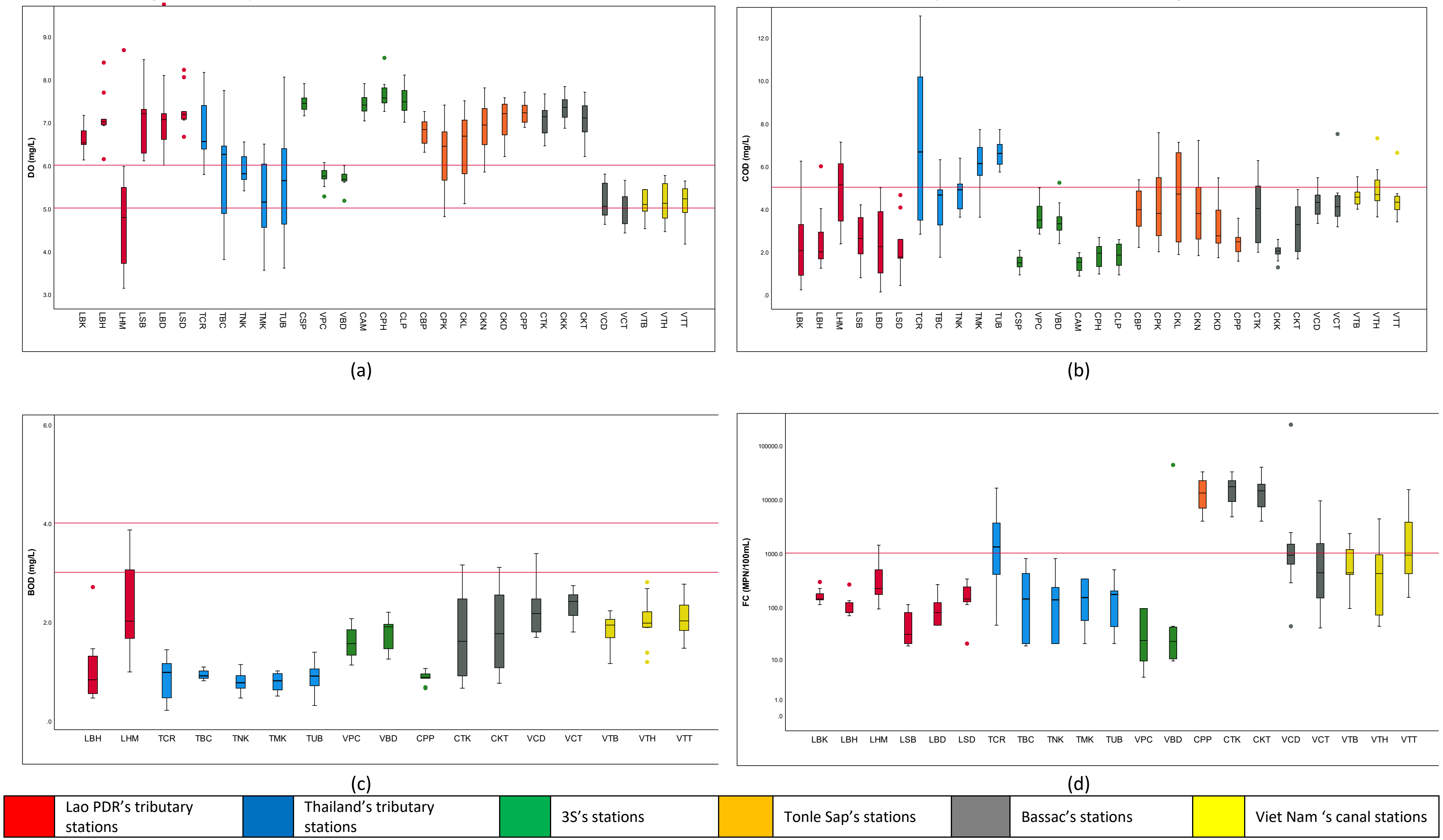



**Figure 3.6.** Spatial distribution of (a) DO, (b) COD, (c) BOD and (d) FC levels at key tributaries of the Mekong River in 2021

### 3.3.2 Temporal variations of water quality

Given that the key monitoring objective of routine WQMN in 2021 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 for water quality parameters with concentrations exceeded and/or noncompliance 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 to Table 3.2, and include EC, DO, COD, BOD and FC. Their temporal variations are discussed in detailed below.

#### 3.3.2.1 Electrical Conductivity

Electrical conductivity is one of the useful water quality indicators monitored by the MRC WQMN. It provides valuable baseline that has been used to identify any emerging effects of development on water quality in the Mekong River. It is also the most important parameter in determine the suitability of the Mekong River water for irrigation uses (Gholami & Srikantaswamy, 2009). In the LMB, the electrical conductivity 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.

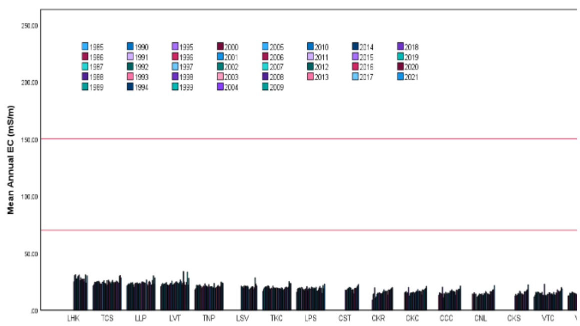
Under normal circumstance and in areas that are not affected by salinity intrusion, the Mekong and Bassac Rivers, similar to other waterbodies, have constant ranges of conductivity, and therefore, any sudden and significant change in electrical conductivity can be an indicator of water pollution (Pal et al., 2015; USEPA, 2014a). Similar to other water quality indicators, EC levels in a river are influenced by both natural and human-induced factors (USEPA, 2014a). Under natural condition, 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. color, 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 electrical conductivity level.

The Mekong River and its tributaries are naturally low-salinity rivers with EC values rarely exceeded 50 mS/m when monitored during low tide. In 2021, 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), Ubon (TUB), and My Tho (VMT) whcih exceeded 70 mS/m (Sections 3.1.1 and 3.1.3).

On a temporal scale, high EC had been observed in the Delta (Vietnam's stations) during high tide due to the backwater effects of seawater, and had been recorded with a maximum value of 841.0 mS/m. This maximum value was recorded at VMT in April 1998. Outside of the values recorded during the high tide, annual EC levels at VMT have not rarely exceeded the 150 mS/m threshold of the WQGH since the WQMN began monitoring water quality at the station during low tide starting from 2005 (Figure 3.7a). Since 2005, the mean annual EC concentration at VMT has increased significantly from about 37 mS/m (2005) to 54.4 mS/m (2021). The increase was determined to be statistically significant with 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, instream EC level at LHM has 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, 74.7 mS/m in 2021, and 82.8 mS/m. This increase was also determined to be statistically significant by ANOVA statistical analysis with the p-value of 0.01. As discussed in Sections 3.1.3 and 3.3.1.2, LHM is located on Houay Mak Hiao – a stream that monitor drainage and runoff from the City of Vientiane, and may have been influenced by urbanization as suggested by Okamoto et al. (2014) and Ly et al. (2020). Aside from VMT, statistically increasing trends of EC were also detected by ANOVA and Seasonal Mann-Kendall at all Tonle Sap Basin stations (CBP, CPK, CKL, CKN, CKD and CPP) and Viet Nam's Delta stations (VTB, VTH, VTT, VCD, and VCT). However, mean annual instream concentrations at these stations were still well below 70 mS/m – the lower target value of the WQGH (Figure 3.7d, e and f).

At TUB – the other station with measured EC value of greater than 70 mS/m in 2021, the maximum EC concentration of 143.15 mS/m was recorded in June 2021. Despite this maximum concentration, the mean annual EC concentration at TUB in 2021 was about 40.1 mS/m compared to 27.8 mS/m in 2020 and 21.6 mS/m in 2004 when the station was first integrated into the WQMN. While the overall temporal trends have been steadily increased, the changes were found to be statistically insignificant by both ANOVA and Seasonal Mann-Kendall test with p-values of 0.78 and 0.49, respectively.

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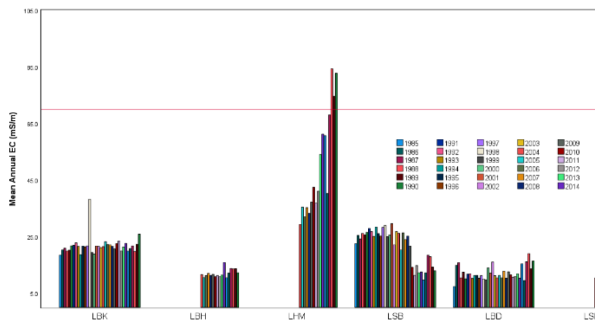


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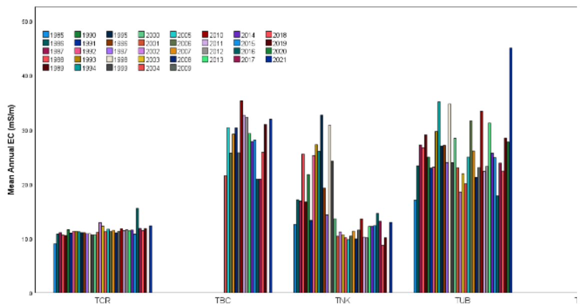


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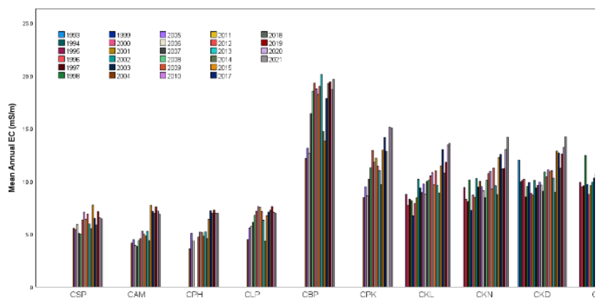


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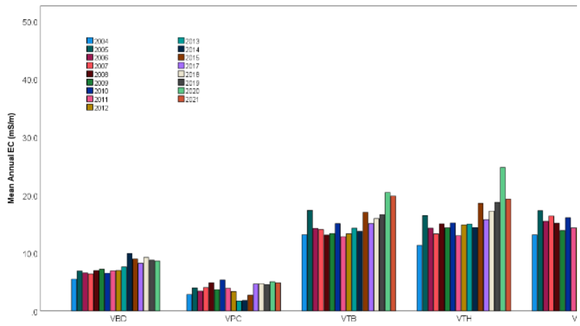
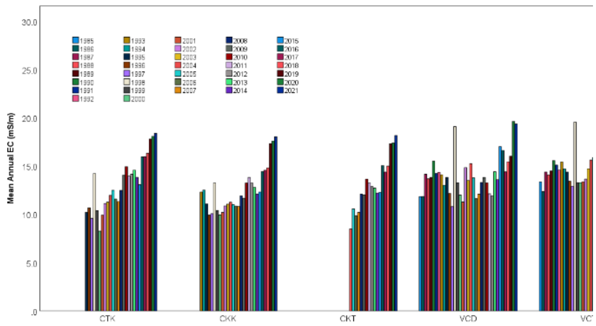



(e)




(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 dissolved oxygen at the individual 48 mainstream and tributary stations are shown in Figure 3.8 below. Temporal assessment of DO trends at these 48 stations by ANOVA and Seasonal Mann-Kendall test have revealed that DO concentrations have decreased significantly at 15 stations, including VTC, VMH, and VMT in the mainstream, LBK of Lao PDR's tributary, TNK, TUB, and TMK of Thailand's tributaries, and all seven (7) tributary stations in Viet Nam, including the two stations (VCD and VCT) on the Bassac River.

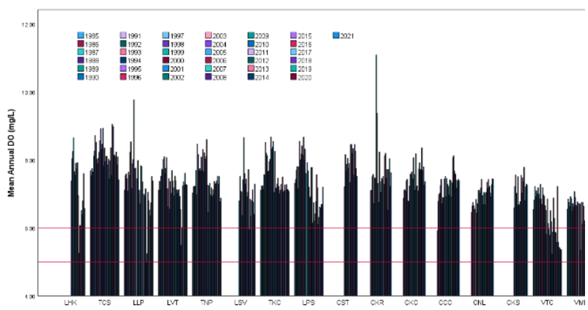
Of significant concerns are DO levels at the eight (8) stations located in the Viet Nam's Delta where a combined 31.3% of the measured DO concentrations were lower than the target value of WQGA (5 mg/L). Furthermore, about 99% of DO concentrations recorded in 2021 were lower than the target value of WQGH (6 mg/L). Compared to 2020 when a combined 42.7% of concentrations were lower than 5 mg/L, water quality in Viet Nam's Delta for the protection of aquatic life, with respect to DO, improve slightly in 2021. With respect to the protection of human health, water quality in Viet Nam's delta remained large unchanged when compared to 2020 using DO as a proxy for water quality with 96.9% of recorded DO concentrations lower than 6 mg/L. Temporally, the decreasing trend detected for instream DO concentrations in Viet Nam's Delta has been statistically significant with ANOVA and Seasonal Mann-Kendall's p-values of less than 0.01 calculated for all eight (8) stations. For comparisons, in 2005 when the eight (8) stations were fully integrated in the current WQMN, only 1.2% and 28.6% of DO concentrations were recorded to be lower than the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively.

With Pearson's correlation analyses confirm statistically significant negative relationships between instream DO and instream COD, EC, NO3-2, TOTP, COD and BOD at p-values of 0.01, the decreased in DO levels at these stations were the results of the increased levels of instream COD, EC, NO3-2, TOTP, COD and BOD. Studies around the world (Poudel et al., 2010; Schuetz et al., 2016; Vandeberg et al., 2015; Vrebos et al., 2017; Yu et al., 2016), including many in the LMB (Ly et al., 2020; Oeurng et al., 2016), 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. Prolong reduction in DO levels can lead to a number of environmental issues including the decline in biodiversity of aquatic species and/or even worse killed (Nong et al., 2021; Uriarte et al., 2011; USEPA, 2012a). Given the current non-integration of the WQMN with other MRC environmental monitoring disciplines, including ecological health and fisheries monitoring, it is current 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 carried following the WQMN redesign as part of the Core River Network Monitoring.

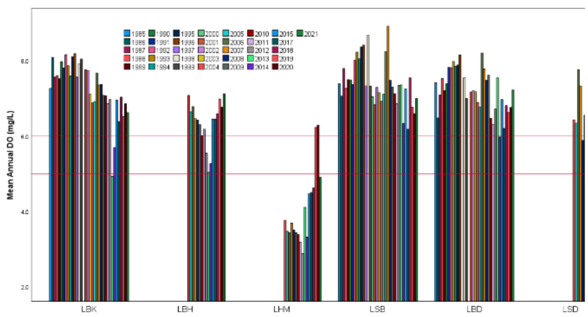
Further to the eight (8) Viet Nam's Delta stations as mentioned, the two Viet Nam's Central Highland stations – Pleicu and Ban Don – should also be further investigated. It should be noted that in 2021, a combined 96% of DO concentrations at these two stations were recorded to be lower than the target values of WQGH (6 mg/L), respectively. It should be noted, however, that all DO concentrations at both stations were higher than 5 mg/L. In 2005 when the two stations were first fully monitored monthly, all DO concentrations were recorded to be higher than 6 mg/L.

Aside from the stations located Viet Nam's national boundary, water quality with respect to DO levels are also of concerns at Houay Mak Hiao (LHM) and at Mun at Khong Chiam (TMK). At LHM, about 56 and 89% of DO concentrations were recorded to be lower than the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively. The low DO levels at this station in 2021 were directly correlated with the elevated levels of TOTN, COD, and EC. However, it should be noted that DO levels at LHM have been historically low when compared to the target values of WQGA and WQGH with the mean annual concentration value of 3.8 mg/L in 2004 when the station was first integrated into the WQMN. For comparison, the mean annual concentration values of DO were estimated to be 4.4 and 4.9 mg/L. The increasing trends observed at this station is not statistically significant with p-values for both ANOVA and Seasonal Mann-Kendall being greater than 0.05.

At TMK, about 50 and 67% of DO concentrations were recorded to be lower than the target values of WQGA (5 mg/L) and WQGH (6 mg/L), respectively. In comparison, only about 18.2 and 45.5% of DO concentrations were lower than the same target values, respectively, in 2020. Temporally, both Seasonal Mann-Kendall and ANOVA have determined the decreased DO trends to be statistically insignificant with p-values greater than 0.05. In 2004 when the station was first integrated into the WQMN, mean annual DO concentration value was estimated to be about 5.8 mg/L. This value was estimated to be about 5.1 mg/L in 2021.




(a)

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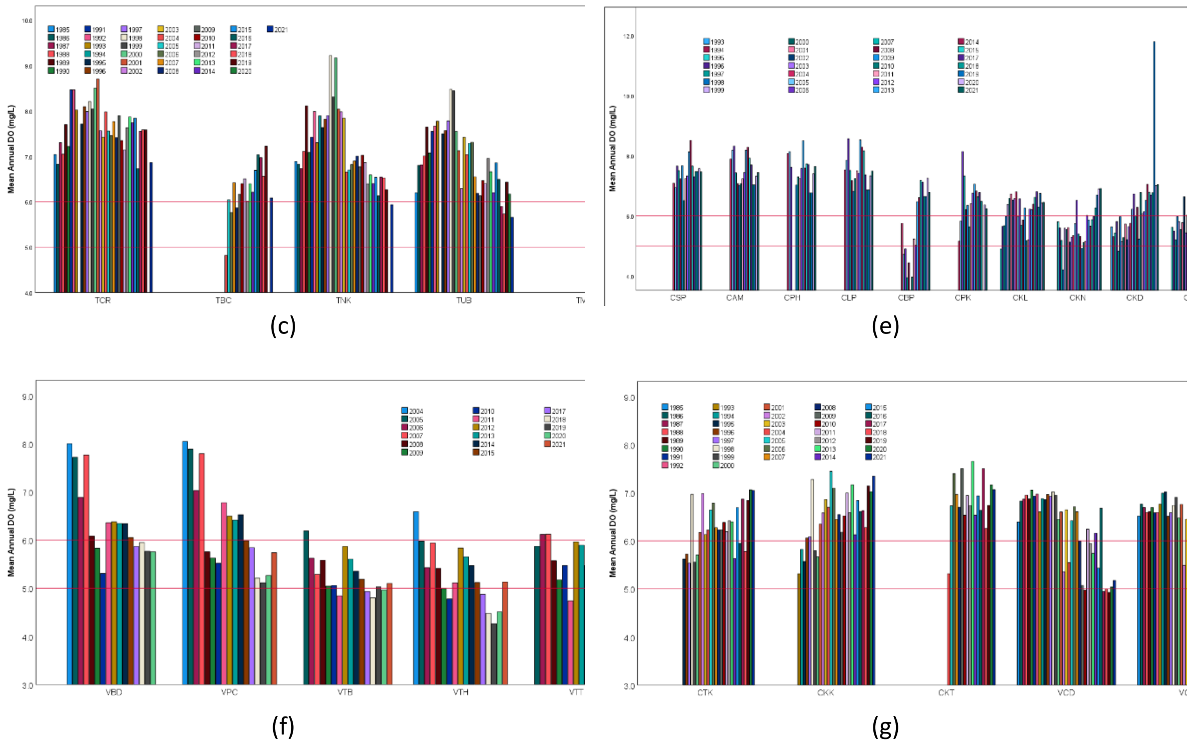

**Figure 3.8.** Temporal variation of mean annual DO levels of 48 water quality monitoring stations along (a) the Mekong River; (b) Lao PDR's tributary stations; (c) Thailand's tributary stations; (d) Cambodia's tributary stations; (e) Viet Nam's tributary stations; and (f) Bassac River's stations.

#### 3.3.2.3 Chemical Oxygen Demands

COD have 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 water quality. As listed in Table 2.3, potassium permanganate is used to chemically oxidize organic material in 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 Seasonal Mann-Kendall test reveal that COD levels have statistically increased at many mainstream and tributaries stations. In mainstream, both ANOVA and Seasonal Mann-Kendall confirm that statistically significant increasing trends were detected at all but six (6) stations. The six stations with decreasing temporal trends were all located in Cambodia section of the mainstream river, although these decreasing trends were not statistically significant with p-values of Season Mann-Kendall ranged from 0.32 to 0.81 and p-values for ANOVA of greater than 0.05.

Of the 11 mainstream stations exhibited increasing trends, seven (7) stations were assessed by Seasonal Mann-Kendall test to be statistically significant at the p-value of less than 0.01. These stations include TCS, LLP, LVT, TNP, VTC, VMH and VMT, which all located either downstream or within the urban areas 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 recorded mean annual COD concentration greater than 5 mg/L in 2021 (Figure 3.9a).

Along the tributary stations, a number of stations recorded COD concentrations of concerns in 2021 including at Chiang Rai (TCR), Houay Mak Hiao (LHM), Ubon (TUB), and Mun at Khong Chiam (TMK), where their mean annual COD concentrations exceeded the target value of the WQGH (5 mg/L) (Figure 3.9b and c).

At LHM, COD levels have always been consistently elevated although fluctuation of COD mean annual concentrations have been detected since the station was first integrated into the WQMN in 2005. Despite mean annual concentration of 4.8 mg/L, the temporal COD trend at LHM had increased, with both ANOVA and Seasonal Mann-Kendall test revealing the increased trend to be statistically significant at p-values of 0.05 levels. For comparison, the recorded mean annual COD concentration at LHM was 6.54 mg/L in 2005. The value increased to 7.7 mg/L in 2020 but decreased to 4.8 mg/L in 2021.

Instream COD levels at TUB had also increased significantly with both ANOVA and Seasonal Mann-Kendall test estimate the increased to be statistically significant at p-values of 0.05 and 0.01, respectively. At TUB, the annual average instream COD concentration was recorded to be 2.74 mg/L in 1986 with no concentration exceeded the target value of WQGH (5 mg/L)[10]. In 2021, the annual average COD concentration had increased to 6.6 mg/L with 100% of the measured COD concentration exceeded 5 mg/L (the target value of WQGH). For a comparison, the annual average COD concentration at this station in 2020 was 5.45 mg/L with 36% of concentrations exceeded the target value of WQGH. Since 2005 when the average annual COD concentration first exceeded the target value of WQGH, COD at TUB has been highly variable values ranged from 0.34 mg/L (May 2004) to 20.6 mg/L (March 2004), with average concentration for the period for 2004-2021 about 4.70 mg/L and 55.2% exceedance rate of the WQGH target value (5 mg/L). For comparison, from 1985 to 2003, the average COD value was about 2.95 mg/L with 0% percent exceedance of the WQGH.

Aside from TUB, two other tributary stations within Thailand's national boundary recorded annual average COD concentrations of greater than 5 mg/L. These stations were Mun at Khong Chiam (TMK) and Chiang Rai (TCR) where their annual average COD concentrations were estimated to be 6.04 and 6.8 mg/L, respectively. At TMK, COD concentrations were measured to range from 3.6 to 7.7 mg/L, whereas the COD concentration range at TCR was recorded from 2.8 to 13.1 mg/L. Overall, approximately 83 and 58% of COD concentrations measured at TMK and TCR, respectively, exceeded the target value of WQGH (5 mg/L). Temporally, instream COD levels at these two stations have also increased significantly with ANOVA and Seasonal Mann-Kendall's p-values of less than 0.05. For comparison, the average annual COD concentrations at TMK and TCR in 1986[11] were 3.3 and 1.5 mg/L, respectively.

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

[11] TMK and TCR are two of the original stations of the WQMN, established in 1985, but the first full year of monitoring was carried out in 1986.

With instream COD being a known proxy for organic pollution from industrial, human, and animal wastes (Lee et al., 2016; Lee & Bang, 2000), the increased instream COD levels at LHM, TCR, TUB, TMK may be a reflection of increase urbanization and industrialization in the respective sub-basins.

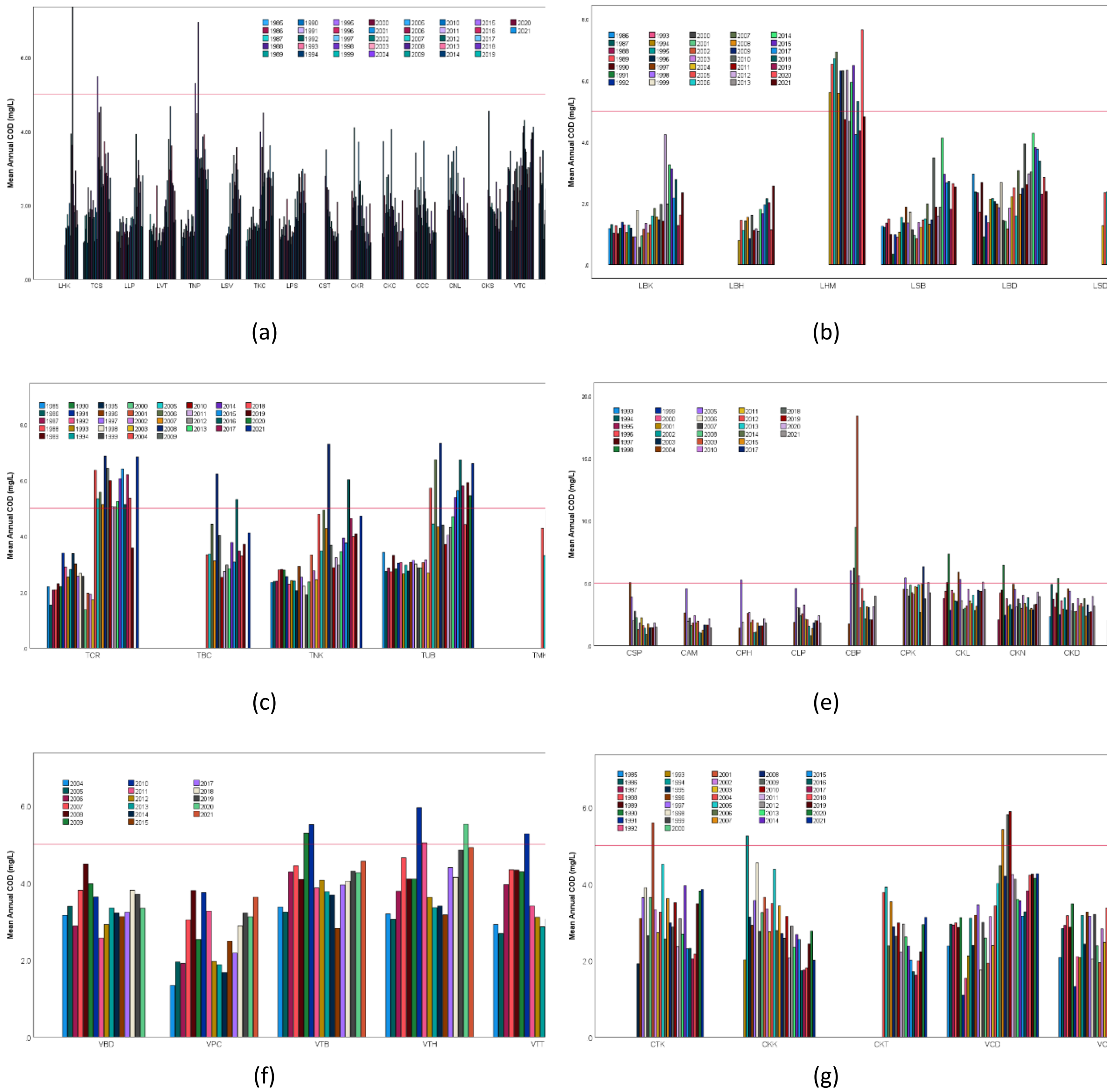
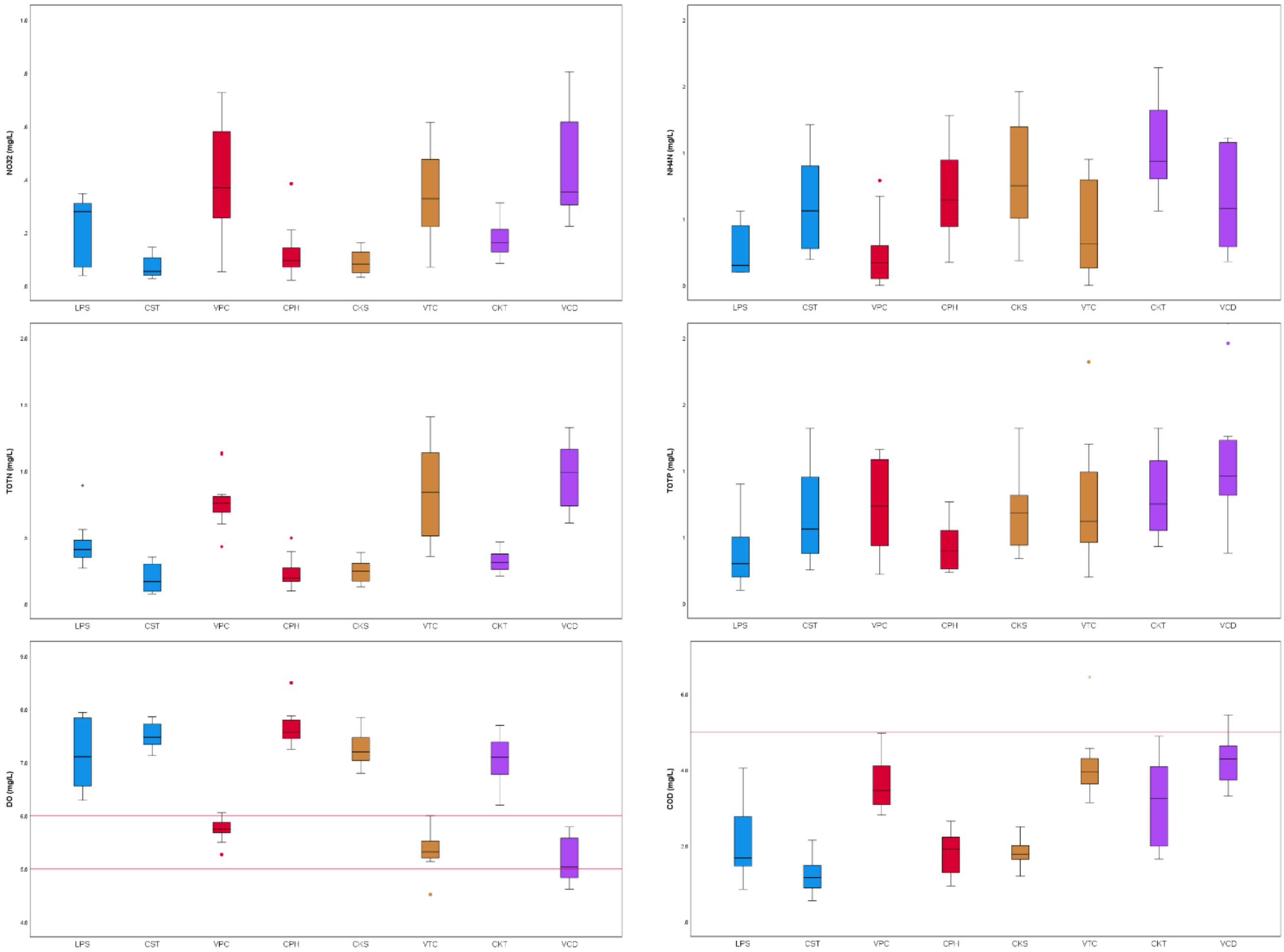



**Figure 3.9.** Temporal variation of mean annual COD levels of 48 water quality monitoring stations along (a) the Mekong River; (b) Lao PDR's tributary stations; (c) Thailand's tributary stations; (d) Cambodia's tributary stations; (e) Viet Nam's tributary stations; and (f) Bassac River's stations

## 3.4 Transboundary Water Quality

Four (4) sets of transboundary water quality monitoring are considered as part of this regional report, comprising eight (8) 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). For this report, the focus of transboundary water quality issues is on instream nutrient pollution, including $NO_{3-2}$, $NH_4N$, TOTN, TOTP, DO, and COD, as illustrated in Figure 3.10.




Transboundary stations of Pakse (LPS) vs. Stung Treng (CST)
Transboundary stations of Pleicu (VPC) vs. Phum Phi (CPH)
Transboundary stations of Kraorm Samnor (CKS) vs. Tan Chau (VTC)
Transboundary stations of Koh Thom (CKT) vs. Chau Doc (VCD)

**Figure 3.10.** Comparisons of 2021 water quality data at the designated transboundary stations of WQMN

### 3.4.1 Pakse vs. Stung Treng

Figure 3.10 suggests potential transboundary water quality issue between Pakse (LPS) and Stung Treng (CST) in term of $NH_4N$ with levels of these indicators widely different between the upstream and downstream stations. The results of t-test revealed that the differences in mean concentrations of $NH_4N$ at LPS and CST were statistically significant with the p-values of 0.031 (Table 3.4). In 2021, $NH_4N$ levels at LPS ranged from 0.01 to 0.06 mg/L, with an average concentration 0.03 mg/L (Std = 0.02). In comparison, $NH_4N$ levels measured at CST in 2021 ragned from 0.02 to 0.12 mg/L with an average concentration of 0.06 mg/L (Std = 0.04).

The differences in levels of both $NH_4N$ between LPS (upstream station) and CST (downstream station) could indicate potential transboundary water quality issue and need to be further investigated. The investigation should be carried at CST to determine whether the sources of the elevated instream $NH_4N$ 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.

Aside from $NH_4N$, the results of t-test also revealed that the differences in mean concentrations of $NO_{3-2}$, DO, and COD were statistically significant with p-values ranged from 0.000 to 0.025 (Table 3.4). For $NO_{3-2}$ and COD, instream concentrations of these parameters were found to be generally higher at the upstream station (LPS) compared to downstream station (CST), indicating that instream pollutants detected at LPS were not transported to CST. Conversely, instream DO concentrations were measured to be generally higher at CST (M = 7.51, Std = 0.24) compared the concentrations measured at LPS (M = 7.20, Std = 0.68).

**Table 3.4.** Statistical analyses of nutrient parameters monitored at LPS and CST in 2021

| Indicators | Stations | Mean (mg/L) | Std. Deviation | p-values |
|---|---|---|---|---|
| $NO_{3-2}$ | LPS | 0.20 | 0.13 | 0.000 |
| | CST | 0.07 | 0.04 | |
| $NH_4N$ | LPS | 0.03 | 0.02 | 0.031 |
| | CST | 0.06 | 0.04 | |
| TOTN | LPS | 0.46 | 0.18 | 0.426 |
| | CST | 0.19 | 0.11 | |
| TOTP | LPS | 0.04 | 0.03 | 0.222 |
| | CST | 0.07 | 0.04 | |
| DO | LPS | 7.20 | 0.68 | 0.000 |
| | CST | 7.51 | 0.24 | |
| COD | LPS | 2.07 | 1.00 | 0.025 |
| | CST | 1.23 | 0.48 | |

### 3.4.2 Pleicu vs. Phum Phi

Pleicu (VPC) and Phum Phi (CPH) are located on the Se San River and form part of the 3S River System that enter the Mekong River at the 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 serve as an 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 explorative assessment of levels of the four (4) nutrient water quality indicators at Pleicu (VPC) and Phum Phi (CPH) was carried which revealed no potential transboundary water quality issue in 2021, with levels of all four indicators measured to be higher in the upstream stations then downstream stations (Figure 3.10). Table 3.5 provides a statistical summary of data of $NO_{3-2}$, $NH_4N$, TOTN, TOTP, DO and COD at these two stations. While concentration levels of the four water quality indicators were different at VPC and CPH, the differences were found to be statistically significant for only $NO_{3-2}$ and TOTP with p-value of 0.020 and 0.022, respectively.

**Table 3.5.** Statistical analyses of nutrient parameters monitored at VPC and CPH in 2021

| Indicators | Stations | Mean (mg/L) | Std. Deviation | p-value |
|---|---|---|---|---|
| $NO_{3-2}$ | VPC | 0.39 | 0.22 | 0.020 |
| | CPH | 0.13 | 0.09 | |
| NH4N | VPC | 0.02 | 0.03 | 0.105 |
| | CPH | 0.07 | 0.04 | |
| TOTN | VPC | 0.78 | 0.20 | 0.346 |
| | CPH | 0.24 | 0.11 | |
| TOTP | VPC | 0.12 | 0.14 | 0.022 |
| | CPH | 0.04 | 0.02 | |
| DO | VPC | 5.74 | 0.20 | 0.216 |
| | CPH | 7.65 | 0.33 | |
| COD | VPC | 3.63 | 0.68 | 0.565 |

### 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 being on the Cambodian side and VTC being on the Vietnamese side and serve as a downstream location of the two transboundary stations. To assess potential transboundary water quality issues at these two stations, a comparison and exploratory analyses were carried out on four nutrient indicators ($NO_{3-2}$, $NH_4N$, TOTN and TOTP), as well as DO and COD. The outcomes of these analyses are illustrated in Figure 3.10.

**Table 3.6.** Statistical analyses of nutrient parameters monitored at CKS and VTC in 2021

| Indicators | Stations | Mean (mg/L) | Std. Deviation | p-value |
|---|---|---|---|---|
| $NO_{3-2}$ | CKS | 0.09 | 0.05 | 0.000 |
| | VTC | 0.35 | 0.16 | |
| NH4N | CKS | 0.08 | 0.04 | 0.404 |
| | VTC | 0.06 | 0.07 | |
| TOTN | CKS | 0.24 | 0.08 | 0.000 |
| | VTC | 0.84 | 0.34 | |
| TOTP | CKS | 0.07 | 0.03 | 0.193 |
| | VTC | 0.07 | 0.05 | |
| DO | CKS | 7.25 | 0.30 | 0.848 |
| | VTC | 5.36 | 0.38 | |
| COD | CKS | 1.82 | 0.35 | 0.143 |
| | VTC | 4.12 | 0.84 | |

In general, water quality in the Mekong River in term of NO3-2, TOTN, TOTP, and COD in 2021 was more degraded in VTC than CKS. For instance, in 2021, generally higher levels of these parameters were observed at Tan Chau than at Kaorm Samnor, which indicated the possibility of transboundary water quality issue. Statistically, t-tests revealed that there were significant differences in levels of NO3-2 and TOTN at these two stations with the P values of less than 0.000 (Table 3.6). In 2021, the average NO3-2 concentrations at CKS was 0.09 mg/L (Std = 0.05) compared to 0.35 mg/L (Std = 0.16) at VTC. Likewise, the average TOTN concentration at CKS was 0.24 mg/L (Std = 0.08) compared to 0.84 mg/L (Std = 0.34).

Aside from NO3-2 and TOTN, instream levels of TOTP and COD were also measured to be higher at VTC than at CKS. However, the results of the t-test revealed their mean differences to not be statistically significance with p-values of greater than 0.05 (Table 3.6).

With instream DO having been established to have negative correlations with NO3-2, TOTN, TOTP, and COD (Section 3.2 and Table 3.3), higher mean DO concentration was recorded at CKS (M = 7.25, Std = 0.30) compared to the mean concentration at VTC (M = 5.36, Std = 0.38). However, the difference in mean DO concentrations between the two station was determined to be statistically insignificant with p-value of 0.848 (Table 3.6).

### 3.4.4 Koh Thom vs. Chau Doc

Similar analysis was carried out for Koh Thom (CKT) (on the Cambodian side of the river) and Chau Doc (VCD) (on the Vietnamese side of the river) water quality monitoring stations on the Bassac River to explore potential transboundary water quality issues. *Figure 3.10* illustrates the comparisons of the concentrations of $NO_{3-2}$, $NH_4H$, TOTN, TOTP, DO and COD recorded at CKT and VCD monitoring stations in 2021.

**Table 3.7.** Statistical analyses of nutrient parameters monitored at CKT and VCD in 2021

| Indicators | Stations | Mean (mg/L) | Std. Deviation | p-value |
|---|---|---|---|---|
| $NO_{3-2}$ | CKT | 0.17 | 0.06 | 0.000 |
| | VCD | 0.45 | 0.21 | |
| $NH_4N$ | CKT | 0.10 | 0.03 | 0.064 |
| | VCD | 0.09 | 0.10 | |
| TOTN | CKT | 0.32 | 0.08 | 0.022 |
| | VCD | 1.03 | 0.42 | |
| TOTP | CKT | 0.08 | 0.03 | 0.278 |
| | VCD | 0.11 | 0.05 | |
| DO | CKT | 7.06 | 0.41 | 0.604 |
| | VCD | 5.18 | 0.40 | |
| COD | CKT | 3.13 | 1.19 | 0.005 |
| | VCD | 4.27 | 0.63 | |

In terms of pollutant levels, Figure 3.10 shows that concentrations of $NO_{3-2}$, TOTN, and COD were slightly higher in the downstream station (VCD) than the upstream station (CKT) in 2021. Opposite pattern was detected for DO with CKT recorded mean DO concentration of 7.06 mg/L (Std = 0.41) compared to 5.18 mg/L (Std = 0.40) at VCD. However, the result of t-test revealed the difference in mean DO concentrations between the two stations to be statistically insignificant with p-value of 0.604.

On the other hand, the differences in mean concentrations of $NO_{3-2}$, TOTN, and COD were determined to be statistically significant with p-values ranging from 0.000 to 0.022 (Table 3.7). Individually, COD concentrations were generally recorded to be higher and less variable at VCD (M = 4.27, Std = 0.63) compared to the concentrations recorded at CKT (M = 3.13, Std = 1.19).

Likewise, instream levels of $NO_{3-2}$ in the Bassac River were found to be higher at VCD when compared to CKT. At VCD, $NO_{3-2}$ concentrations were measured to range from 0.22 to 0.81 mg/L with mean annual concentration of 0.45 mg/L (Std = 0.21) in 2021. In comparison, instream $NO_{3-2}$ concentrations at CKT were measured to range from 0.08 to 0.31 mg/L with mean annual concentration of 0.17 mg/L (Std = 0.06).

In freshwater environment, $NO_{3-2}$ is one of the primary food sources for algae (Poor & McDonnell, 2007; USEPA, 2014b). Limited amount of nitrate is available naturally in freshwater environment which generally balances nutrient needs of the aquatic ecosystem and algae growth. Persistently elevated nitrate levels, which 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 & McDonnell, 2007; USEPA, 2014b).

## 3.5 WATER QUALITY INDICES

Water quality status of the Mekong River and its tributaries in 2021 for the protection of human health, the protection of aquatic life, and agricultural use (general irrigation and paddy irrigation) are highlighted on Table 3.8 with detailed discussions in Sections 3.5.1 to 3.5.3.

**Table 3.8.** Water quality status of the Mekong River and its tributaries for the protection of human health, the protection of aquatic life, and agricultural use as of 2021

| Station Abbr. | Station Names | River Names | $WQI_{hh}$ | $WQI_{al}$ | $WQI_{ag}$ (general irrigation) | $WQI_{ag}$ (paddy irrigation) |
|---|---|---|---|---|---|---|
| LHK | Houa Khong | Mekong | A | A | A | A |
| TCS | Chiang Sean | Mekong | B | B | A | A |
| LLP | Luang Prabang | Mekong | A | A | A | A |
| LVT | Vientiane | Mekong | A | A | A | A |
| TNP | Nakhon Phanom | Mekong | B | A | A | A |
| LSV | Savannakhet | Mekong | A | A | A | A |

| Station Abbr. | Station Names | River Names | $WQI_{hh}$ | $WQI_{al}$ | $WQI_{ag}$ (general irrigation) | $WQI_{ag}$ (paddy irrigation) |
|---|---|---|---|---|---|---|
| TKC | Khong Chaim | Mekong | B | A | A | A |
| LPS | Pakse | Mekong | A | A | A | A |
| CST | Stung Treng | Mekong | A | 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 | B | B | A | A |
| VMH | My Thuan | Mekong | B | B | A | A |
| VMT | My Tho | Mekong | C | C | B | A |
| **Lao PDR's Tributaries** | | | | | | |
| LBK | Ban Hatkham | Nam Ou | B | A | A | A |
| LBH | Ban Hai | Nam Ngum | B | A | A | A |
| LSD | Sedone bridge | Sedone | A | A | A | A |
| LSB | Se Bangfai | Se Bangfai | A | A | A | A |
| LBD | Ban Kengdone | Se Banghieng | A | A | A | A |
| LHM | Houay Mak Hiao | Houay Mak Hiao | C | C | 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 | C | B | A | A |
| TMK | Mun (Kong Chiam) | Mun | C | B | A | A |
| **Tonle Sap River Basin** | | | | | | |
| CBP | Backprea | Tonle Sap | B | 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 | A | A | A | A |
| **3S River Basin** | | | | | | |
| VPC | Pleicu | Se San | A | B | A | A |
| VBD | Ban Don | Sre Pok | B | B | A | A |
| CPH | Phum Pi | Se San | A | A | A | A |
| CAM | Angdoung Meas | Se San | A | A | A | A |
| CLP | Lumphat | Sre Pok | A | A | A | A |
| CSP | Siempang | Se Kong | A | A | A | A |
| **Viet Nam's Canal** | | | | | | |
| VTT | Tu Thuong | Tu Thoung | B | B | A | A |
| VTH | Thong Binh | Thong Binh | B | C | A | A |
| VTB | Tinh Bien | Tinh Bien | B | B | A | A |

| Station Abbr. | Station Names | River Names | $WQI_{hh}$ | $WQI_{al}$ | $WQI_{ag}$ (general irrigation) | $WQI_{ag}$ (paddy irrigation) |
|---|---|---|---|---|---|---|
| **Bassac River** | | | | | | |
| CTK | Takhmao | Bassac | B | B | A | A |
| CKK | Koh Khel | Bassac | A | A | A | A |
| CKT | Koh Thom | Bassac | A | A | A | A |
| VCD | Chau Doc | Bassac | B | B | A | A |
| VCT | Can Tho | Bassac | B | 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 2021, water quality of the Mekong and its tributaries were rated from "moderate" to "high" quality 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 Lao PDR/China national boundary to Cambodia/Viet Nam national boundary were assessed to be of "high" quality for the protection of aquatic life. At these 14 stations (including TCS), a merely 1.6% (15 data point out of 929 data points) of water quality data exceeded their respective target values. Of this 1.6%, 40% (6 out of 15 exceedance data points) was data from TCS. At TCS, water quality for the protection of aquatic life was rated as "good" quality with about 50% of $NO_{3-2}$ data exceeded the target value used for $WQI_{al}$ (0.5 mg/L) with the maximum $NO_{3-2}$ concentration being 0.62 mg/L (July 2021). No other exceedance was recorded at TCS in 2021.

Also rated as "good" quality in the mainstream were water quality conditions at Tan Chau (VTC) and My Thuan (VMH). These two stations, about 7.6% of a combined data was recorded to exceed their respective target values. Among the indicators used for calculating WQIal, $NO_{3-2}$ was measured to exceed its target value of 0.5 mg/L at 25% while 12.5% of the TOTP concentrations were recorded to be lower than the target value for WQGA (0.13 mg/L).

Also in the mainstream, water quality for the protection of aquatic life at My Tho (VMT) was rated as "moderate" quality which was attributed to a number of exceedances of key water quality indicators. Specifically, 58.3% of $NO_{3-2}$ measured at VMT exceeded 0.5 mg/L (target value used for $WQI_{al}$ calculation (Table 2.4)) while 42% of TOTP data exceeded 0.13 mg/L (also target value used for $WQI_{al}$ calculation (Table 2.4)). Reduced level of DO (42% below target value of WQGA (5 mg/L)) also contributed to the "moderate" rating of water quality for the protection of aquatic life at My Tho.

Compared to 2020 (please refer to **Annex B**), water quality for the protection of aquatic life did not change any of the 17 mainstream stations with each station receiving the same rating in 2021 as in 2020.
Along the tributaries of the Mekong River, water quality conditions at 11 stations were rated as "high" quality for protection of aquatic life while 17 and 3 stations received "good" and "moderate" rating, respectively. The three (3) stations receiving "moderate" rating were Houay Mak Hiao (LHM), Ubon (TUB), Mun at Khong Chiam (TMK). At these three (3) stations, a combined 11.4% of data points (23 out of 202 data point) exceeded the respective target value used for $WQI_{al}$, with 45% of a combined DO data felt below the target value of WQGA (5 mg/L). As discussed in Section 3.1.2, elevated EC and $NO_{3-2}$ also contributed to water quality at LMH to be slightly impaired for the protection of aquatic life. At LMH, about 22.4% of water quality data exceeded their respective target values in 2021. Of this 22.4% exceedance, 54% was caused by $NO_{3-2}$ concentrations which exceeded its target value of 0.5 mg/L at 78%.

### 3.5.2 Water Quality Index for the Protection of Human Health

Analysis of the 2021 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 ranged from "moderate" or "excellent" quality (Table 3.8). Along the mainstream, 14 stations were rated as "excellent" for the protection of human health including all but one station (Chiang Sean (TCS)) located upstream of Cambodia and Viet Nam's national boundary.

Along with Chiang Sean, water quality at Tan Chau (VTC) and My Thuan (VMH) was rated as "good" quality for the protection of human health. At these three stations, 17% of COD concentrations exceeded the target value used for $WQI_{hh}$ calculation (5 mg/L) with the extent of these exceedances recorded to range between 0.04 to 0.39 mg/L with the total extent of exceedance of 0.34 mg/L (Equation 2.5).

The lone mainstream station not to be rated either "good" or "excellent" quality is My Tho (VMT), which was rated as "moderate" quality for the protection of human health. At VMT, exceedances were recorded for pH, EC and COD concentration, with 25% of COD concentrations recorded in 2021 exceeded 5 mg/L.

Along the tributaries, water quality at three (3) stations were also rated as "moderate" quality for the protection of human health, including water quality at LHM (a tributary station of Lao PDR), Thong Binh (a canal station located in Viet Nam's Mekong Delta), and Can Tho (a tributary station located in the Bassac River). At LHM, about 56% of COD concentrations exceeded 5 mg/L (target value of WQGH) while 33.3% of DO concentrations were recorded to be lower than the target value used for $WQI_{hh}$ calculation (Table 2.6).

Overall, water quality at 44 stations (of the 48 WQMN stations) was rated as either "good" or "excellent" for the protection of human health. However, it should be noted that the formula used does not factor into faecal coliform (FC) levels which were highly elevated at many stations include those located on the mainstream and within Cambodia's national boundary (please refer to Sections 3.1.1 and 3.3.1.1 for more discussion on FC). Therefore, direct

consumption of water from the Mekong River should be done with care and in accordance with the guidelines of the World Health Organization (WHO, 2011).
Compared to 2020 (please refer to **Annex C**), water quality for the protection of human health improved slightly at three (3) mainstream stations including at Vientiane (LVT), Pakse (LPS) and Stung Treng (CST). At these three (3) stations, $WQI_{al}$ rating improved from "good" quality in 2020 to "high" quality in 2021. Conversely, the mainstream water quality for the protection of human health decreased at four (4) stations including at Chiang Sean (TCS), Nakhon Phnom (TNP) and Tan Chau (VTC), where the rating for water quality for the protection of human health reduced from "excellent" quality in 2020 to "good" quality in 2021. At My Tho (VMT), water quality for the protection of human health was rated as "moderate" quality in 2021, down from the rate of "good" quality it received in 2020.

### 3.5.3 Water Quality Index for Agricultural Use

The level of impairment of 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 electrical conductivity (Table 2.8).

An analysis of electrical conductivity data from 2021 revealed that outside of the levels recorded at My Tho (VMT) (Sections 3.1.1) and Houay Mak Hiao (LMH) (Section 3.1.2), all electrical conductivity values fell within the guideline value for Water Quality Index for General Irrigation Use of 70 mS/m. As such, water quality of the Mekong River and its tributaries were rated as "no restriction" for the general irrigation use at 46 stations (Table 3.8).

The only two stations with water quality condition that post restriction to general irrigation use purposes were VMT and LMH. In 2021, water quality at both stations was found to have "some restriction" for general irrigation use but "no restriction" for paddy irrigation (Table 3.8).

From 2008 to 2021, water quality of the Mekong River and its tributaries remained suitable for both general and paddy rice irrigation purposes, with the annual $WQI_{ag}$ ratings of mostly "no-restriction" (**Annex D**). The only exception being in 2016 and 2021 at My Tho (VMT) which resulted from a prolonged seawater intrusion (**Annex D**), as invested as part of the regional study on the extent of salinity intrusion.

## 3.6 Operational Effects of Mainstream Hydropower on Water Quality of the Mekong River

Recognizing the potential effects of hydropower development and/or operation on the Mekong River water quality, the MRC and its Member Countries piloted the Joint Environment Monitoring Programme (JEM) between 2019 to 2021. Under JEM, water quality was one of the five environmental monitoring disciplined piloted at 10 locations upstream, within and downstream Xayaburi and Don Sahong Hydropower Projects – the two current operational mainstream hydropower projects (MRC, 2020). While the pilot of JEM has come to a completion, monitoring of the Mekong River water quality downstream of Don Sahong (DS) Hydropower Project continued in 2022 with the installation and operation of an automated high frequency water quality (HFWQ) monitoring station which located downstream of Don Sahong Dam Site. At Don Sahong (DS) HFWQ monitoring station, five (5) water quality parameters relevant to the operation of hydropower project have been monitored including water temperature, pH, EC, DO, and Turbidity, as recommended by JEM Programme (MRC, 2022).

As part of this report, available data from DS HFWQ has been collated and analysed to assess operational impacts of Don Sahong Hydropower Project. Table 3.9 provides a summary of water quality conditions of the Mekong River downstream of Don Sahong Dam Site. Specifically, results of the analysis of available water quality data from DS HFWQ reveal that pH and DO levels were well within their respective target values of WQGH and WQGA (Table 3.9). At DS HFWQ, pH concentrations were measured to range from 6.4 to 8.1 with an average value of 7.1. In comparison, the recommended target range of WQGH and WQGA for pH is 6 to 9. Likewise, DO concentrations were measured to range from 7.83 to 8.38 mg/L, with an average value of about 8.1 mg/L. Compared to other nearby mainstream stations (Pakse (LPS) and Stung Treng (CST)), pH and DO concentrations at DS HFWQ were comparatively similar to those at LPS and CST. At LPS, pH and DO concentrations were recorded to range from 6.8 to 8.3 and 6.3 to 7.9 mg/L, respectively, while pH and DO concentrations at CST were recorded to range from 7.3 to 7.9 and 7.1 to 7.9 mg/L, respectively (please refer to Annex A).

Aside from pH and DO, EC was also monitored at DS HFWQ with concentration ranged from 25 to 30 mS/m and an average concentration of 28.6 mS/m. These levels were comparatively similar to those recorded at other mainstream stations (Annex A), with the exception of the levels at My Tho (VMT) where EC concentrations were seasonally affected by salinity intrusion from the East Sea (Section 3.1.1).

**Table 3.9.** Descriptive statistics of water quality data from the automated high frequency water quality monitoring station downstream of Don Sahong Hydropower Project (DS HFWQ)[12]

| Station | Statistical Parameters | TEMP (°C) | pH | Turbidity (FNU) | COND (mS/m) | DO (mg/L) |
|---|---|---|---|---|---|---|
| **TGWQ** | **Chapter 1: WQGH** | - | 6 – 9 | - | 70 - 150 | ≥ 6 |
| | **Chapter 2: WQGA** | - | 6 – 9 | - | - | > 5 |
| DS HFWQ | Max | 31.7 | 8.1 | 154.09 | 30.00 | 8.38 |
| | Mean | 29.3 | 7.1 | 39.16 | 28.57 | 8.08 |
| | Min | 26.6 | 6.4 | 16.55 | 25.00 | 7.83 |
| | Std. | 1.2 | 0.3 | 15.70 | 0.84 | 0.10 |

[12] Water quality data from DS HFWQ was collated for the monitoring period between March to August 2022.

While not monitoring by the WQMN (Table 2.3), turbidity is monitored at DS HFWQ as it was deemed as an important water quality parameter for detecting operational impacts of hydropower project (MRC, 2020). The operational effects of hydropower project have been well studied and documented in many regions (Finger et al., 2006; Robb et al., 2021; Tomczyk & Wiatkowski, 2021; von Sperling, 2012). At DS HFWQ, turbidity concentrations were recorded to be highly variable and ranged from 16.55 to 154.09 mg/L, with the greatest concentrations correlated to rainfall events in the vicinity.

Overall, water quality parameters monitored at DS HFWQ were highly correlated (Table 3.10) with all relationships mirrored those exhibited by data collected at the 48 WQMN stations (Table 3.3). Specifically, pH and DO were found to be highly correlated with Pearson's correlation value of 0.9 at significant level of 0.01 (2-tailed) (Table 3.10). For comparison, the Pearson's correlation value of pH and DO from the 48 WQMN stations was 0.265 at p-value of 0.01 (2-tailed) (Table 3.3). These relationships along with the results outlined in Table 3.9 confirmed that the operation of Don Sahong Hydropower Project did not affect water quality of the Mekong River (in relation to water temperature, pH, turbidity, ED and DO) during this monitoring period.

**Table 3.10.** Relationships among key water quality parameters monitored by Don Sahong High Frequency Water Quality Monitoring Station in 2022

| Water Quality Parameters | Temp (°C) | pH | Turbidity (FNU) | EC (mS/m) | DO (mg/L) |
|---|---|---|---|---|---|
| Temp (°C) | | | | | |
| pH | .157** | | | | |
| EC (mS/cm) | -0.024 | .113** | | | |
| Turbidity (FNU) | -.742** | -.124** | | | |
| DO (mg/L) | .350** | .900** | -.272** | .142** | |

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

# 4. CONCLUSIONS AND RECOMMENDATIONS

## 4.1 CONCLUSIONS

This report provides an overall basin-wide assessment of water quality of the Mekong River and its tributaries in the 2021, using key water quality parameters monitored under the MRC WQMN and listed in Chapter 1 and 2 of the TGWQ as proxies for water quality. The analyses of water quality data collected from 48 monitoring stations were carried out for this report using 19 key monitoring parameters and a variety of statistical analysis techniques. Of these 48 stations, 17 were located along Mekong River, 5 along Bassac River, and 26 in other key tributaries of the Mekong River.

Based on the assessment results of the 2021 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 2021 varied spatially with water quality for the protection of human health rated from "moderate" to "excellent" water quality. Overall, water quality at 44 stations was rated as either "good" or "excellent" for the protection of human health while water quality at four stations was rated as "moderate" for the protection of human health. Of the four stations rated as "moderate" quality, three were located in the tributaries of Lao PDR and Thailand, where instream water quality continued to be periodically affected by elevated electrical conductivity and/or COD levels and reduced DO levels. These stations are located downstream of major urban centres, with LHM receiving effluents from the Vientiane Municipality while TUB and TMK receiving runoffs from Nakhon Ubon Ratchathani. Likewise, water quality at VMT was rated "moderate" for the protection human health and continued to be affected by seasonal elevated EC levels, as well as reduced instream DO concentrations.
- Elevated faecal coliform (FC) concentrations continued to be recorded in 2021 at many mainstream and tributaries stations including at CKC, CCC, CPP, CTK and CKT, where 100% of FC concentrations exceeded the target value of WQGH. With 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 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). While water quality at all but four (4) stations were rated as either "good" or "excellent" for the protection of human health, elevated faecal coliform (FC) levels should be considered when utilizing the Mekong River and its tributaries as portable water with the World Health Organization guideline be strictly observed (WHO, 2011).
- With regard to the protection of aquatic life, water quality of the Mekong and its tributaries at the 48 stations of the WQMN was rated to range from "moderate" to "high" quality with all but one mainstream station located upstream of Cambodia and Viet Nam's national boundaries being rated as "high" quality. The lone mainstream

station in this stretch of the mainstream not to receive “high” quality in 2021 was TCS, where elevated $NO_{3-2}$ levels were detected. Among the 17 mainstream stations, only water quality at VMT was rated “moderate” quality for the protection of aquatic life and continued to be affected to elevated nutrient and/or reduced DO levels. Along with VMT, two other tributary stations located in Viet Nam’s Delta (VTH and VCT) also received a rating of “moderate” quality for the protection of aquatic life.

- Water quality at VTM continued to be seasonally influenced by salinity intrusion in 2021. However, 2021 EC data suggested that the influence was less severe compared to 2020 when water quality was found to be severely restricted for both general and paddy irrigation uses. In 2021, water quality at VTM was determined to have no restriction of use for paddy irrigation but posed some restriction for general irrigation use. In addition to VTM, water quality at LHM also posed some restriction for general irrigation use but had no restriction for paddy irrigation use. Aside from these two stations, water quality of the Mekong and its tributaries continued to pose no restriction to agricultural use.
- 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 were measured to exceed the target values of either WQGH, WQGA, $WQI_{hh}$ and/or $WQI_{al}$.
- Using dissolved oxygen 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/or aquatic life with dissolved oxygen continued to be one of the key water quality issues for many stations in 2021. The reduction in DO levels were directly the results from the increased levels of EC, $NO_{3-2}$, TOTP, COD or BOD. The monitoring of these parameters, along with DO will need to be more intensive and may need to include special investigation to explore potential point and non-point sources of these pollutants.
- In term of potential transboundary water quality issues in 2021, the analyses of $NO_{3-2}$, $NH_4N$, TOTN, TOTP, DO and COD suggested potential transboundary water quality issue between CKT and VCD with elevated $NO_{3-2}$, TOTN and COD at VCD compared to those at CKT. Likewise, potential transboundary water quality issues were also detected between CKS and VTC with elevated $NO_{3-2}$ and TOTN concentration recorded at CKS compared to those at VTC. The differences in mean concentration were found to be statically significant.
- The analyses of data from DS HFWQ revealed that the operation of Don Sahong Hydropower Project did not affect the Mekong River water quality pertaining to instream levels of pH, DO, EC and turbidity. Specifically, all concentrations of pH and DO were found to well within their respective target values for WQGH and WQGA. EC concentrations were found to be similar to those recorded at other mainstream stations, with the exception being VMT.

## 4.2 RECOMMENDATIONS

Member Countries’ efforts to maintain “acceptable/good” water quality of the Mekong and its tributaries require the compliance of water quality set in the Procedure for Water Quality and its associated Technical Guidelines (TGWQ). In addition to the 19 parameters monitored in 2021, Chapters 1 and 2 of the TGWQ lists several additional water quality indicators that need to be monitored in the near future, including heavy metal and pesticide indicators. These indicators have been added taking into consideration emerging threats to water quality, including population growth, intensive agriculture, aquaculture and land use, navigation, irrigation, hydropower and industrialisation, which 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 national and regional levels to improve the capacity of the line agencies responsible for water quality monitoring. In addition, concerted efforts will also be required to develop cost-effective monitoring methodology 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 and operation on water quality, Riverine Plastic Debris Monitoring and Assessment, and the Multi-Media Monitoring and Assessment of the Mekong Riverine. The lessons learnt from the implementation of these specific water quality monitoring activities, along with the anticipated increase development in the LMB, have renew focus and question on the relevancy of the current WQMN in terms of its objectives, spatial coverage in relation to other existing environmental monitoring programmes, monitoring frequency for timely detection of emerging threats, and relevancy of data to support the assessment of basin-wide development. As part the MRC Core River Monitoring Network, the WQMN is under review to ensure its complementary to the MCs and MRC's other environmental monitoring activities for meeting regional needs.

Considering the status of water quality as highlight in this regional report, the ongoing 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 concerns to ensure timely detection of further changes so that any potential effects on human health and aquatic life can be timely detected and remedied;
- Investigate the causes and eventually the effects of water quality impairment on the aquatic fauna and ecosystem, particularly at stations where water quality has been identified as either "moderate" 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 learnt from both the dry and wet season pilots for the integration into the WQMN;
- Support and advocate for the integration of macro and microplastic monitoring into the routine water quality monitoring network 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 report;
- Advocate and support the Member Countries in the timely identification and sharing information on water quality incident that may constitutes an emergency through the implementation of 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 Chapter 1 and Chapter 2 of the TGWQ including heavy metals as well as persistent and non-persistent organic substances, as part of the overall review of the implementation of the Procedures for Water Quality and its technical guidelines;
- Through the review of the MRC Core River Monitoring Network, explore the feasibility on the establishment of 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, etc.), including the feasibility of water quality monitoring by both automated high frequency water quality monitoring system and manual monitoring stations with parameters that are proxies for algae bloom;
- Advocate and provide supports to the Member Countries for the continuation of water quality monitoring at stations excluded from the CRMN, as part of the overall implementation of the WQMN and PWQ.
- In line with the recommendations of the JEM Programme and the objectives of the CRMN, continue monitoring the long-term effects of hydropower development and operation on the mainstream water quality including identifying any potential transboundary water quality issues.
- Strengthen capacity 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 existing and planned hydropower dams, and the monitoring of hydropower specific water quality indicators, including chlorophyll and cyanobacteria, as recommended by JEM;
- Continue monitoring the effect of salinity intrusion in the Mekong Delta through the installation of automated high frequency water quality monitoring stations as recommended by the CRMN. Data obtained from these stations can be used to support regional study on the extent of salinity intrusion in the Mekong's Delta for the preparation of future State of the Basin Report.
- Continue support and advocate the importance of QA/QC for water quality monitoring, through the provisions of training, validation of data, development and maintenance of monitoring Standard Operating Procedures, and Proficiency Testing;
- Advocate and support the strengthening of cooperation among the Member Countries for water quality monitoring through technical exchange of WQMN laboratories' staff;
- Assist national designated laboratories in achieving ISO/IEC 17025 certificates which will enable laboratories to demonstrate that they operate competently and generate valid results, thereby promoting confidence in the monitoring results nationally, regionally and globally.

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# Annex a – 2021 water quality status of the Mekong River as monitored at 17 mainstream stations

| Stations[13] | 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) | BOD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TGWQ | Chapter 1: WQGH | - | 6 – 9 | - | 70 - 150 | 5 | - | - | - | ≥ 6 | 5 | 4 |
| | Chapter 2: WQGA | - | 6 – 9 | - | - | 5 | - | - | - | > 5 | - | 3 |
| Chiang Sean | Maximum | 24.0 | 7.1 | 83.1 | 28.3 | 0.5 | 0.1 | 0.8 | 0.1 | 8.3 | 3.6 | 0.9 |
| | Mean | 23.5 | 6.8 | 59.5 | 27.7 | 0.5 | 0.1 | 0.7 | 0.1 | 7.7 | 2.9 | 0.7 |
| | Median | 23.5 | 6.8 | 59.5 | 27.7 | 0.5 | 0.1 | 0.7 | 0.1 | 7.7 | 2.9 | 0.7 |
| | Minimum | 23.0 | 6.5 | 35.8 | 27.0 | 0.5 | 0.0 | 0.6 | 0.0 | 7.2 | 2.2 | 0.5 |
| | Std. Deviation | 0.7 | 0.5 | 33.4 | 0.9 | 0.0 | 0.0 | 0.1 | 0.0 | 0.8 | 1.0 | 0.3 |
| Chrouy Changvar | Maximum | 30.6 | 7.9 | 110.4 | 26.2 | 0.2 | 0.1 | 0.4 | 0.1 | 7.9 | 1.7 | 0.9 |
| | Mean | 30.1 | 7.6 | 44.2 | 21.2 | 0.1 | 0.1 | 0.2 | 0.1 | 7.4 | 1.3 | 0.8 |
| | Median | 30.3 | 7.5 | 22.8 | 21.3 | 0.1 | 0.0 | 0.1 | 0.1 | 7.4 | 1.3 | 0.8 |
| | Minimum | 29.4 | 7.3 | 3.6 | 18.7 | 0.0 | 0.0 | 0.1 | 0.0 | 7.1 | 0.9 | 0.6 |
| | Std. Deviation | 0.4 | 0.2 | 43.0 | 2.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.3 | 0.3 | 0.1 |
| Houa Khong | Maximum | 28.9 | 8.1 | 178.0 | 35.9 | 0.3 | 0.0 | 1.7 | 0.1 | 7.0 | 3.3 | |
| | Mean | 24.0 | 7.6 | 50.6 | 30.1 | 0.2 | 0.0 | 0.8 | 0.0 | 6.6 | 1.5 | |

[13] Stations are arranged in alphabetical order and not in the order from upstream to downstream locations

| Stations[13] | 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) | BOD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TGWQ** | **Chapter 1: WQGH** | - | 6 – 9 | - | 70 - 150 | 5 | - | - | - | ≥ 6 | 5 | 4 |
| | **Chapter 2: WQGA** | - | 6 – 9 | - | - | 5 | - | - | - | > 5 | - | 3 |
| | Median | 22.8 | 7.7 | 27.3 | 30.8 | 0.2 | 0.0 | 0.6 | 0.1 | 6.8 | 1.6 | |
| | Minimum | 21.9 | 7.0 | 11.9 | 22.4 | 0.1 | 0.0 | 0.4 | 0.0 | 6.0 | 0.1 | |
| | Std. Deviation | 2.4 | 0.4 | 54.9 | 4.4 | 0.1 | 0.0 | 0.4 | 0.0 | 0.4 | 1.1 | |
| Kampong Cham | Maximum | 30.8 | 7.9 | 220.0 | 25.2 | 0.1 | 0.2 | 0.4 | 0.1 | 7.8 | 2.1 | 0.9 |
| | Mean | 30.0 | 7.6 | 64.8 | 20.9 | 0.1 | 0.1 | 0.2 | 0.1 | 7.4 | 1.4 | 0.7 |
| | Median | 30.1 | 7.6 | 40.4 | 20.8 | 0.1 | 0.0 | 0.1 | 0.1 | 7.3 | 1.4 | 0.6 |
| | Minimum | 29.3 | 7.3 | 3.7 | 18.2 | 0.0 | 0.0 | 0.1 | 0.0 | 6.9 | 0.8 | 0.4 |
| | Std. Deviation | 0.6 | 0.2 | 74.2 | 2.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.3 | 0.4 | 0.2 |
| Kaorm Samnor | Maximum | 31.2 | 8.0 | 166.6 | 26.6 | 0.2 | 0.1 | 0.4 | 0.1 | 7.9 | 2.5 | |
| | Mean | 29.9 | 7.6 | 59.0 | 22.2 | 0.1 | 0.1 | 0.2 | 0.1 | 7.2 | 1.8 | |
| | Median | 29.8 | 7.6 | 37.1 | 22.2 | 0.1 | 0.1 | 0.2 | 0.1 | 7.2 | 1.8 | |
| | Minimum | 28.4 | 7.3 | 8.0 | 19.4 | 0.0 | 0.0 | 0.1 | 0.0 | 6.8 | 1.2 | |
| | Std. Deviation | 0.8 | 0.2 | 55.5 | 2.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.3 | 0.3 | |
| Khong Chiam | Maximum | 30.5 | 8.5 | 370.6 | 29.9 | 0.5 | 0.2 | 0.7 | 0.1 | 8.5 | 6.7 | 1.7 |
| | Mean | 27.4 | 7.5 | 70.9 | 23.5 | 0.3 | 0.1 | 0.5 | 0.0 | 7.1 | 2.9 | 0.6 |
| | Median | 28.0 | 7.4 | 28.2 | 25.2 | 0.4 | 0.0 | 0.5 | 0.0 | 6.9 | 2.8 | 0.5 |
| | Minimum | 21.5 | 6.6 | 3.3 | 12.1 | 0.0 | 0.0 | 0.2 | 0.0 | 6.4 | 0.9 | 0.0 |
| | Std. Deviation | 2.8 | 0.6 | 104.7 | 6.0 | 0.2 | 0.0 | 0.2 | 0.0 | 0.7 | 1.6 | 0.4 |

| Stations[13] | 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) | BOD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TGWQ | **Chapter 1: WQGH** | - | 6 – 9 | - | 70 - 150 | 5 | - | - | - | ≥ 6 | 5 | 4 |
| | **Chapter 2: WQGA** | - | 6 – 9 | - | - | 5 | - | - | - | > 5 | - | 3 |
| Kratie | Maximum | 30.6 | 7.8 | 160.8 | 23.8 | 0.2 | 0.1 | 0.4 | 0.1 | 8.1 | 1.6 | |
| | Mean | 29.9 | 7.6 | 46.7 | 19.9 | 0.1 | 0.1 | 0.2 | 0.1 | 7.6 | 1.0 | |
| | Median | 29.8 | 7.7 | 20.7 | 20.5 | 0.0 | 0.0 | 0.1 | 0.0 | 7.6 | 0.9 | |
| | Minimum | 29.3 | 7.2 | 2.9 | 16.6 | 0.0 | 0.0 | 0.1 | 0.0 | 7.2 | 0.6 | |
| | Std. Deviation | 0.5 | 0.2 | 49.9 | 2.2 | 0.0 | 0.0 | 0.1 | 0.0 | 0.3 | 0.3 | |
| Luang Prabang | Maximum | 28.8 | 7.9 | 297.8 | 46.2 | 0.6 | 0.0 | 1.3 | 0.1 | 8.1 | 4.9 | |
| | Mean | 26.4 | 7.5 | 88.5 | 28.2 | 0.3 | 0.0 | 0.6 | 0.0 | 7.4 | 2.8 | |
| | Median | 26.3 | 7.5 | 62.6 | 28.1 | 0.3 | 0.0 | 0.5 | 0.0 | 7.3 | 3.8 | |
| | Minimum | 22.4 | 7.1 | 2.9 | 18.2 | 0.0 | 0.0 | 0.3 | 0.0 | 6.8 | 0.1 | |
| | Std. Deviation | 2.2 | 0.3 | 100.4 | 8.6 | 0.2 | 0.0 | 0.3 | 0.0 | 0.5 | 2.0 | |
| My Tho | Maximum | 29.9 | 7.9 | 118.0 | 194.5 | 1.0 | 0.3 | 1.6 | 0.2 | 5.9 | 6.3 | 4.3 |
| | Mean | 28.7 | 7.3 | 45.2 | 54.4 | 0.6 | 0.2 | 0.9 | 0.1 | 5.0 | 4.4 | 2.6 |
| | Median | 28.7 | 7.4 | 41.5 | 25.8 | 0.6 | 0.1 | 0.9 | 0.1 | 5.2 | 4.3 | 2.5 |
| | Minimum | 26.8 | 5.9 | 14.0 | 14.4 | 0.1 | 0.0 | 0.5 | 0.0 | 4.0 | 3.3 | 1.7 |
| | Std. Deviation | 0.9 | 0.5 | 28.8 | 65.7 | 0.3 | 0.1 | 0.3 | 0.1 | 0.6 | 0.8 | 0.7 |
| My Thuan | Maximum | 30.0 | 7.4 | 111.0 | 26.4 | 0.7 | 0.3 | 2.0 | 0.2 | 5.8 | 6.7 | 3.9 |
| | Mean | 28.6 | 7.0 | 40.3 | 19.5 | 0.4 | 0.1 | 1.1 | 0.1 | 5.3 | 4.9 | 2.3 |
| | Median | 28.6 | 7.1 | 29.0 | 19.4 | 0.4 | 0.0 | 1.0 | 0.1 | 5.3 | 4.8 | 2.1 |

| Stations[13] | 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) | BOD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TGWQ** | **Chapter 1: WQGH** | - | 6 – 9 | - | 70 - 150 | 5 | - | - | - | ≥ 6 | 5 | 4 |
| | **Chapter 2: WQGA** | - | 6 – 9 | - | - | 5 | - | - | - | > 5 | - | 3 |
| | Minimum | 27.1 | 6.7 | 11.0 | 13.4 | 0.1 | 0.0 | 0.7 | 0.0 | 4.5 | 3.2 | 1.3 |
| | Std. Deviation | 0.8 | 0.2 | 28.1 | 4.3 | 0.1 | 0.1 | 0.4 | 0.0 | 0.3 | 1.3 | 0.6 |
| Nakhon Phanom | Maximum | 29.0 | 8.2 | 92.9 | 29.6 | 0.4 | 0.1 | 0.7 | 0.1 | 8.9 | 5.4 | 1.1 |
| | Mean | 26.1 | 7.4 | 39.3 | 23.6 | 0.4 | 0.1 | 0.5 | 0.0 | 6.9 | 3.0 | 0.8 |
| | Median | 27.0 | 7.5 | 25.3 | 24.1 | 0.3 | 0.1 | 0.6 | 0.0 | 6.7 | 3.4 | 0.8 |
| | Minimum | 17.0 | 6.5 | 9.7 | 14.5 | 0.2 | 0.0 | 0.3 | 0.0 | 5.9 | 1.5 | 0.3 |
| | Std. Deviation | 3.5 | 0.5 | 29.3 | 4.3 | 0.1 | 0.0 | 0.1 | 0.0 | 0.9 | 1.4 | 0.2 |
| Neak Loung | Maximum | 30.7 | 8.0 | 143.5 | 25.2 | 0.1 | 0.1 | 0.3 | 0.1 | 7.8 | 1.7 | |
| | Mean | 29.9 | 7.6 | 51.1 | 21.6 | 0.1 | 0.0 | 0.2 | 0.1 | 7.4 | 1.2 | |
| | Median | 29.8 | 7.6 | 40.0 | 22.1 | 0.1 | 0.0 | 0.1 | 0.0 | 7.4 | 1.2 | |
| | Minimum | 28.9 | 7.2 | 3.6 | 17.6 | 0.0 | 0.0 | 0.1 | 0.0 | 7.2 | 0.8 | |
| | Std. Deviation | 0.6 | 0.2 | 49.9 | 2.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.2 | 0.3 | |
| Pakse | Maximum | 28.8 | 8.3 | 116.5 | 26.8 | 0.3 | 0.1 | 0.9 | 0.1 | 7.9 | 4.1 | |
| | Mean | 26.4 | 7.5 | 40.3 | 22.8 | 0.2 | 0.0 | 0.5 | 0.0 | 7.2 | 2.1 | |
| | Median | 27.4 | 7.4 | 21.2 | 25.1 | 0.3 | 0.0 | 0.4 | 0.0 | 7.1 | 1.7 | |
| | Minimum | 22.8 | 6.8 | 5.5 | 16.9 | 0.0 | 0.0 | 0.3 | 0.0 | 6.3 | 0.9 | |
| | Std. Deviation | 2.2 | 0.5 | 40.1 | 4.2 | 0.1 | 0.0 | 0.2 | 0.0 | 0.7 | 1.0 | |
| Savannakhet | Maximum | 31.0 | 7.5 | 216.3 | 38.3 | 0.4 | 0.0 | 0.8 | 0.1 | 9.6 | 4.1 | |

| Stations[13] | 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) | BOD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TGWQ | **Chapter 1: WQGH** | - | 6 – 9 | - | 70 - 150 | 5 | - | - | - | ≥ 6 | 5 | 4 |
| | **Chapter 2: WQGA** | - | 6 – 9 | - | - | 5 | - | - | - | > 5 | - | 3 |
| | Mean | 26.9 | 7.2 | 51.9 | 21.1 | 0.2 | 0.0 | 0.4 | 0.0 | 7.3 | 2.3 | |
| | Median | 25.7 | 7.2 | 32.9 | 17.9 | 0.2 | 0.0 | 0.4 | 0.0 | 6.9 | 3.0 | |
| | Minimum | 23.4 | 7.0 | 4.7 | 10.8 | 0.1 | 0.0 | 0.2 | 0.0 | 6.1 | 0.4 | |
| | Std. Deviation | 2.8 | 0.2 | 66.6 | 9.5 | 0.1 | 0.0 | 0.2 | 0.0 | 1.1 | 1.4 | |
| Stung Treng | Maximum | 31.0 | 7.9 | 173.0 | 28.5 | 0.1 | 0.1 | 0.4 | 0.1 | 7.9 | 2.2 | |
| | Mean | 29.8 | 7.6 | 47.3 | 22.5 | 0.1 | 0.1 | 0.2 | 0.1 | 7.5 | 1.2 | |
| | Median | 29.7 | 7.6 | 21.6 | 23.0 | 0.1 | 0.1 | 0.2 | 0.1 | 7.5 | 1.2 | |
| | Minimum | 28.3 | 7.3 | 3.4 | 17.8 | 0.0 | 0.0 | 0.1 | 0.0 | 7.1 | 0.6 | |
| | Std. Deviation | 0.7 | 0.2 | 54.2 | 3.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.2 | 0.5 | |
| Tan Chau | Maximum | 29.9 | 7.8 | 58.0 | 24.5 | 0.6 | 0.2 | 1.4 | 0.2 | 6.0 | 6.5 | 2.5 |
| | Mean | 28.6 | 7.5 | 32.3 | 18.6 | 0.3 | 0.1 | 0.8 | 0.1 | 5.4 | 4.1 | 2.0 |
| | Median | 28.7 | 7.5 | 30.5 | 19.7 | 0.3 | 0.0 | 0.8 | 0.1 | 5.3 | 3.9 | 2.0 |
| | Minimum | 26.8 | 7.2 | 16.0 | 11.0 | 0.1 | 0.0 | 0.4 | 0.0 | 4.5 | 3.1 | 1.6 |
| | Std. Deviation | 0.8 | 0.2 | 12.0 | 4.6 | 0.2 | 0.1 | 0.3 | 0.0 | 0.4 | 0.8 | 0.2 |
| Vientiane | Maximum | 29.5 | 8.4 | 125.7 | 32.9 | 0.4 | 0.0 | 1.8 | 0.1 | 8.5 | 3.9 | 1.7 |
| | Mean | 26.4 | 7.8 | 49.5 | 27.9 | 0.3 | 0.0 | 0.8 | 0.0 | 7.3 | 1.6 | 0.6 |
| | Median | 27.2 | 7.9 | 30.5 | 30.2 | 0.3 | 0.0 | 0.4 | 0.0 | 7.2 | 1.2 | 0.4 |
| | Minimum | 20.9 | 7.1 | 5.0 | 19.0 | 0.2 | 0.0 | 0.4 | 0.0 | 6.4 | 0.4 | 0.3 |

| Stations[13] | 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) | BOD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TGWQ** | **Chapter 1: WQGH** | - | 6 – 9 | - | 70 - 150 | 5 | - | - | - | ≥ 6 | 5 | 4 |
| | **Chapter 2: WQGA** | - | 6 – 9 | - | - | 5 | - | - | - | > 5 | - | 3 |
| | Std. Deviation | 2.9 | 0.4 | 48.9 | 5.2 | 0.1 | 0.0 | 0.6 | 0.0 | 0.8 | 1.1 | 0.5 |
| Total | Maximum | 31.2 | 8.5 | 370.6 | 194.5 | 1.0 | 0.3 | 2.0 | 0.2 | 9.6 | 6.7 | 4.3 |
| | Mean | 28.0 | 7.5 | 51.9 | 25.0 | 0.2 | 0.1 | 0.5 | 0.1 | 6.9 | 2.4 | 1.3 |
| | Median | 28.9 | 7.5 | 31.3 | 22.3 | 0.2 | 0.0 | 0.4 | 0.1 | 7.2 | 1.7 | 0.9 |
| | Minimum | 17.0 | 5.9 | 2.9 | 10.8 | 0.0 | 0.0 | 0.1 | 0.0 | 4.0 | 0.1 | 0.0 |
| | Std. Deviation | 2.7 | 0.4 | 55.9 | 18.5 | 0.2 | 0.1 | 0.4 | 0.0 | 1.0 | 1.6 | 0.9 |

# Annex B – Temporal patterns of water quality of the mekong and Bassac Rivers for the protection of Aquatic Life

| No. | Station Names | Countries | Class | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| 1 | Houa Khong | Laos | A | A | A | A | B | B | B | B | B | B | B | A | A | A |
| 2 | Chiang Saen | Thailand | A | B | B | A | B | B | A | B | B | B | B | A | B | B |
| 3 | Luang Prabang | Laos | A | A | B | A | A | B | B | B | A | B | A | A | A | A |
| 4 | Vientiane | Laos | A | A | A | A | A | B | B | A | A | A | A | A | A | A |
| 5 | Nakhon Phanom | Thailand | B | A | B | A | B | B | A | A | B | B | B | A | A | A |
| 6 | Savannakhet | Laos | A | A | A | A | A | B | B | B | A | A | B | A | A | A |
| 7 | Khong Chiam | Thailand | B | A | A | A | A | B | A | A | A | B | A | A | A | A |
| 8 | Pakse | Laos | A | A | A | A | A | B | B | B | A | A | B | A | A | A |
| 9 | Stung Trieng | Cambodia | B | B | B | B | B | B | B | B | B | A | A | A | A | A |
| 10 | Kratie | Cambodia | B | B | B | B | B | B | B | B | A | B | B | B | A | A |
| 11 | Kampong Cham | Cambodia | B | B | B | B | B | B | A | B | A | A | B | B | A | A |
| 12 | Chrouy Changvar | Cambodia | B | B | B | B | B | B | B | B | A | A | B | B | A | A |
| 13 | Neak Loung | Cambodia | B | B | B | B | B | B | B | B | A | A | B | A | A | A |
| 14 | Kaorm Samnor | Cambodia | B | B | B | B | B | B | B | B | A | A | B | A | A | A |
| 15 | Tan Chau | Viet Nam | B | B | B | B | B | B | B | B | B | A | B | B | B | B |
| 16 | My Thuan | Viet Nam | B | B | B | B | B | B | B | B | B | B | B | B | B | B |
| 17 | My Tho | Viet Nam | C | C | C | C | B | C | C | C | D | C | B | C | C | C |
| 18 | Takhmao | Cambodia | B | B | B | B | B | B | B | B | B | B | B | B | B | B |
| 19 | Koh Khel | Cambodia | B | B | B | B | B | B | B | B | B | B | B | B | B | A |
| 20 | Koh Thom | Cambodia | B | B | B | B | B | B | A | B | B | B | B | A | B | A |
| 21 | Chau Doc | Viet Nam | B | B | B | B | B | B | B | B | B | B | C | C | C | B |
| 22 | Can Tho | Viet Nam | B | C | C | C | C | C | B | B | B | B | B | C | 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

| No. | Station Names | Countries | Class | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| 1 | Houa Khong | Lao PDR | A | A | B | A | B | B | C | A | A | A | B | A | A | A |
| 2 | Chiang Saen | Thailand | B | B | B | A | B | B | B | B | B | B | B | A | A | B |
| 3 | Luang Prabang | Lao PDR | A | A | B | A | B | A | B | B | B | A | B | A | A | A |
| 4 | Vientiane | Lao PDR | A | A | B | A | B | B | B | B | B | A | A | A | B | A |
| 5 | Nakhon Phanom | Thailand | B | B | B | B | B | B | B | B | B | B | B | B | A | B |
| 6 | Savannakhet | Lao PDR | A | A | A | A | B | B | C | B | B | A | A | A | A | A |
| 7 | Khong Chiam | Thailand | B | B | B | A | B | B | B | B | B | B | B | A | B | B |
| 8 | Pakse | Lao PDR | B | A | A | A | A | B | A | B | B | A | A | A | B | A |
| 9 | Stung Trieng | Cambodia | B | A | A | A | A | A | A | A | A | A | A | A | B | A |
| 10 | Kratie | Cambodia | B | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 11 | Kampong Cham | Cambodia | B | A | A | A | A | A | A | B | A | A | A | A | A | A |
| 12 | Chrouy Changvar | Cambodia | B | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 13 | Neak Loung | Cambodia | B | A | A | A | A | A | A | B | A | A | A | A | A | A |
| 14 | Kaorm Samnor | Cambodia | B | A | A | A | B | A | A | B | A | A | A | A | A | A |
| 15 | Tan Chau | Viet Nam | B | C | B | B | A | A | A | A | A | A | B | B | A | B |
| 16 | My Thuan | Viet Nam | B | B | C | A | A | B | A | A | A | B | B | A | B | B |
| 17 | My Tho | Viet Nam | B | C | C | B | B | B | B | A | B | B | B | A | B | C |
| 18 | Takhmao | Cambodia | B | A | A | A | A | B | C | A | B | A | B | B | B | B |
| 19 | Koh Khel | Cambodia | A | A | B | A | B | B | A | B | A | A | A | A | A | A |
| 20 | Koh Thom | Cambodia | B | A | A | A | B | B | A | A | A | A | A | A | A | A |
| 21 | Chau Doc | Viet Nam | B | C | C | B | B | A | A | A | A | B | B | B | A | B |
| 22 | Can Tho | Viet Nam | B | B | C | B | A | A | A | A | A | A | B | A | 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

| No. | Station Names | Countries | Class | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| 1 | Houa Khong | Laos | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 2 | Chiang Saen | Thailand | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 3 | Luang Prabang | Laos | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 4 | Vientiane | Laos | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 5 | Nakhon Phanom | Thailand | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 6 | Savannakhet | Laos | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 7 | Khong Chiam | Thailand | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 8 | Pakse | Laos | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 9 | Stung Trieng | Cambodia | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 10 | Kratie | Cambodia | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 11 | Kampong Cham | Cambodia | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 12 | Chrouy Changvar | Cambodia | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 13 | Neak Loung | Cambodia | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 14 | Kaorm Samnor | Cambodia | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 15 | Tan Chau | Viet Nam | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 16 | My Thuan | Viet Nam | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 17 | My Tho | Viet Nam | A | A | A | A | A | A | A | A | B | A | A | A | C | B |
| 18 | Takhmao | Cambodia | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 19 | Koh Khel | Cambodia | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 20 | Koh Thom | Cambodia | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 21 | Chau Doc | Viet Nam | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| 22 | Can Tho | Viet Nam | A | A | A | A | A | A | A | A | A | A | A | A | A | A |

**A – No Restriction**
**B – Some Restriction**
**C – Severe Restriction**

**Mekong River Commission Secretariat**
184 Fa Ngoum Road, P.O. Box 6101, Vientiane, Lao PDR
T: +856 21 263 263 F: +856 21 263 264
www.mrcmekong.org