2023 LOWER MEKONG WATER QUALITY MONITORING REPORT

August 2024

2023 LOWER MEKONG WATER QUALITY MONITORING REPORT

August 2024

The MRC is funded by contributions from its Member Countries and Development Partners, including Australia, Canada, the European Union, Flanders/Belgium, France, Germany, Japan, Republic of Korea, Luxembourg, the Netherlands, New Zealand, Sweden, Switzerland, the United Kingdom, and the United States of America.

Title: 2023 Lower Mekong Water Quality Monitoring Report

DOI: 10.52107/mrc.CJCXF8

Keywords: water quality/human health/Lower Mekong River Basin/Mekong River Commission/ Spatiotemporal trends

For bibliographic purposes, this volume may be cited as:
Mekong River Commission. (2024). *2023 Lower Mekong Water Quality Monitoring Report*. Vientiane: MRC Secretariat. DOI: 10.52107/mrc.CJCXF8

Information on MRC publications and digital products can be found at
http://www.mrcmekong.org/publication

All queries on rights and licenses should be addressed to:
Mekong River Commission
Education and Visitor 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

CITATION

Mekong River Commission. (2024). *2023 Lower Mekong Water Quality Monitoring Report*. Vientiane: MRC Secretariat. DOI: 10.52107/mrc.CJCXF8

AUTHORS

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

Technical experts:
Dr Phan Nam Long, Water Quality Officer, Environmental Management Division, Mekong River Commission Secretariat
Dr Pinida Lilianna Kamphaengthong, Chief Environmental Management Officer, Environmental Management Division, Mekong River Commission Secretariat
Dr Kongmeng Ly, Ecosystem and Wetland Specialist, Environmental Management Division, Mekong River Commission Secretariat

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 Subdivision, Research Development and Hydrology 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, Vietnam

CONTENTS

FIGURES

TABLES

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
EC	Electrical conductivity
ED	Environmental Management Division
FC	Faecal coliform
HH	Guidelines for the Protection of Human Health
ISO	International Organization for Standardization
LMB	Lower Mekong Basin
MC	Member Country
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NH_4N	Ammonium- nitrogen
NO_{3-2}	Nitrate-nitrite
PWQ	Procedures for Water Quality
QA/QC	Quality assurance/quality control
SM	Standard Methods for Water and Wastewater Examination
TGWQ	Technical Guidelines for the Implementation of the Procedures for Water Quality
TOTN	Total nitrogen
TOTP	Total phosphorus
TSS	Total suspended solids
WQGA	Water Quality Guidelines for the Protection of Aquatic Life
WQGH	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. One of the MRC key environmental monitoring activities within the WQMN is the routine water quality monitoring , which is carried out to support the implementation of the Procedures of Water Quality (PWQ) and its Technical Guidelines. The actual monitoring of water quality is 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 2023, 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 to 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 the key tributaries. The key tributaries are classified as Lao PDR's tributaries (six stations), Thailand's tributaries (five stations), Sekong, Sesan and Srepok (3S) River System (six stations), Tonle Sap River System (six stations), Bassac River System (five 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 (WQIs). The water quality status in 2023 was compared against 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 ($NO_{3\text{-}2}$), 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 2023. The temporal analyses focused on EC, dissolved oxygen (DO) and COD. Potential transboundary water quality issues were also examined for nutrient parameters (NO3-2, NH4N, TOTN, and TOTP), DO and COD at four transboundary sites including 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 2023 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 2023 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 2023 water quality monitoring data at 48 stations indicated that the water quality was good with respect to the target values of focused parameters in the Water Quality Guidelines for the Protection of Human Health (WQGH) and the Water Quality Guidelines for the Protection of Aquatic Life (WQGA). In 2023, water quality significantly improved in terms of DO, especially at the station in Mekong Delta, Viet Nam. Low DO continued to be a concern for water quality at stations in Viet Nam's Mekong Delta.

Forty-six out of 48 stations in the LMB were rated as "good" or "high" according to the WQI for the Protection of Aquatic Life. The "moderate" rating of two stations (Houay Mak Hiao station in Lao PDR's tributaries, and Thong Binh station in Viet Nam's Delta) was due to the elevated concentrations of NO3-2 and TOTP. According to the WQI for the Protection of Human Health, 47 out of 48 stations were rated "good" and "excellent". The only station rated as "moderate", Houay Mak Hiao station in Lao PDR's tributaries, was impacted by the high COD and low DO levels.

The WQI for Agriculture Use rating was "no restriction" and "suitable" for general and paddy rice irrigation, respectively, at all stations in 2023.

From the analysis of water quality data at the transboundary sites, it is suggested that potential transboundary water quality issues may occur at Kaorm Samnor vs. Tan Chau, and Koh Thom vs. Chau Doc. However, the causes of potential transboundary water quality issues were not identified. Therefore, it is crucial to conduct studies to determine the causes of potential transboundary water quality issues at these transboundary sites.

In 2023, according to the MRC WQI, the water quality was rated stable, i.e."acceptable/good". However, the spatial and temporal water quality data have reflected the impacts of human activity from economic development, urbanization and intensive agricultural practices on the degradation of water quality. Therefore, it is crucial to identity the water quality issues and receive instruction by WQMN in responding to these impacts in order to maintain an "acceptable/good" water quality rating in the Mekong River and its key tributaries.

1. INTRODUCTION

1.1 BACKGROUND

Ranked as the 12th longest at approximately 4,880 km and the 8th largest by mean annual discharge at its mouth, with around 14,500 m^3/s (MRC, 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 km^2, the Mekong River Basin can be divided into the Upper Mekong Basin, which comprises an area in China where the Mekong is known as the Lancang River and makes up 23.2% of the total Mekong Basin (186,356 km^2), and the Lower Mekong Basin (LMB), which comprises the area of the Mekong River downstream from the border between China and Lao PDR.

The LMB is functionally subdivided into four broad physiographic regions according to topography, drainage patterns and the geomorphology of river channels – the Northern Highlands, the Khorat Plateau, the Tonle Sap Basin and the Delta. With a total catchment area of around 623,644 km^2, the LMB covers a large part of northeast Thailand, almost the entire part of Lao PDR and Cambodia, and the southern tip of Viet Nam (MRC, 2019).

According to the 2018 State of the Basin Report (MRC, 2019), the Lower Mekong River is home to approximately 70 million people, of whom about 85% live in rural areas where many practise subsistence farming, and supplement their livelihoods and food security with fish catch. The Mekong River is also one of the most biodiverse rivers in the world with an 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. Hence, water quality monitoring is an integral part of detecting changes in the Mekong riverine environment and of 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

Recognizing that sustainable development of water resources of the LMB will not be possible without the effective management of water quality, the MRC Member Countries (MCs) agreed to establish the Water Quality Monitoring Network (WQMN) in 1985, with the specific objectives of monitoring the status and detecting changes in the Mekong River water quality. and ensuring that preventive and remedial actions are taken if any changes are detected. Between 1985 and 1992, the WQMN comprised 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 border.

Since its inception, the WQMN has provided valuable information on the condition of the river water quality, which is essential 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. The assessment showed that there was a need to reduce the cost of the monitoring while increasing its relevancy and suitability in detecting changes associated with the Basin's rapid economic development and population growth. An agreement was reached that the Network would include only primary stations, while the secondary stations would be monitored by individual MCs. "Primary stations" are those 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 on and threats to Mekong water quality. A number of these stations were also strategically selected to detect transboundary water quality problems. In 2023, these stations continued to be monitored by the MCs as part of the WQMN. Of these 48 stations, 17 were located along the Mekong mainstream, while the remaining stations (31) were located in the tributaries of the Mekong River (Section 2.1).

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

Countries	STATID	Station name	Names of water body	Monitoring period		Status*
				Started	Ended	
Cambodia	H014501	Stung Treng	Mekong	10/24/04		A
Cambodia	H014901	Kratie	Mekong	7/11/95		A
Cambodia	H019801	Chrouy Changvar	Mekong	8/12/93		A
Cambodia	H019802	Kampong Cham	Mekong	8/25/93		A
Cambodia	H019806	Neak Loung	Mekong	8/24/93		A
Cambodia	H019807	Kaorm Samnor	Mekong	10/16/04		A
Cambodia	H020101	Phnom Penh Port	Tonle Sap River	7/15/95		A
Cambodia	H020102	Prek Kdam	Tonle Sap River	8/25/93		A
Cambodia	H020103	Kampong Chnang	Tonle Sap River	7/18/95		A
Cambodia	H020106	Kampong Loung	Tonle Sap Lake	7/16/95		A
Cambodia	H020107	Back Prea	Sangkeo (Tonle Sap)	10/21/04		A
Cambodia	H020108	Phnom Krom	Tonle Sap Lake	10/20/04		A
Cambodia	H033401	Takhmao	Bassac River	7/14/95		A
Cambodia	H033402	Koh Khel	Bassac River	8/24/93		A
Cambodia	H033403	Koh Thom	Bassac River	10/16/04		A
Cambodia	H430102	Siem Pang	Se Kong River	10/24/04		A
Cambodia	H440102	Phum Pi	Se San River	11/23/04		A
Cambodia	H440103	Angdoung Meas	Se San River	10/22/04		A
Cambodia	H450101	Lumphat	Sre Pok River	10/22/04		A
Cambodia	H610101	Kampong Thom	Stung Sen River	10/19/04		A
Cambodia	H620101	Kompong Thmar	Stung Chinit River	10/19/04	12/23/08	N
Cambodia	H640110	Kampong Toul	Prek Thnot	7/15/95	12/14/03	N
Lao PDR	H010500	Houa Khong	Mekong	8/17/04		A
Lao PDR	H011200	Luang Prabang	Mekong	7/12/04		N
Lao PDR	H011201	Luang Prabang	Mekong	5/19/85	6/17/04	N

Countries	STATID	Station name	Names of water body	Monitoring period		Status*
				Started	Ended	
Lao PDR	H011901	Vientiane	Mekong	5/15/85		A
Lao PDR	H013401	Savannakhet	Mekong	1/18/01		A
Lao PDR	H013900	Pakse	Mekong	7/15/04		A
Lao PDR	H013901	Pakse	Mekong	7/12/85	6/17/04	N
Lao PDR	H100101	Ban Hatkham	Nam Ou River	6/13/85		A
Lao PDR	H230102	Tha Ngon	Nam Ngum River	5/15/85	6/15/04	N
Lao PDR	H230103	Ban Hai	Nam Ngum River	7/12/04		A
Lao PDR	H230199	Nam Ngum 1 Dam	Nam Ngum River	5/10/85	12/16/08	N
Lao PDR	H230206	Thalath	Nam Lik River	3/14/88	12/16/08	N
Lao PDR	H231801	Nam Souang	Nam Souang River	1/24/01	12/16/08	N
Lao PDR	H231901	Nam Houm	Nam Houm River	2/13/95	12/16/08	N
Lao PDR	H320101	Se Bangfai Bridge	Se Bangfai River	6/18/85	12/16/15	A
Lao PDR	H350101	Ban Kengdone	Se Banghieng River	5/24/85		A
Lao PDR	H390104	Souvannakhili	Sedone River	1/15/89	12/16/08	N
Lao PDR	H390105	Sedone Bridge	Sedone River	7/16/04		A
Lao PDR	H390199	Sedone Dam	Sedone River	5/20/85	12/16/03	N
Lao PDR	H910103	Houa Khoua	That Luong Swamp	8/19/86	12/16/08	N
Lao PDR	H910106	Ban Sok	That Luong Swamp	2/13/95	12/16/08	N
Lao PDR	H910107	Donedeng	That Luong Swamp	1/24/01	12/16/08	N
Lao PDR	H910108	Houay Mak Hiao	Houay Mak Hiao	7/19/04		A
Thailand	H010501	Chiang Sean	Mekong	5/15/85		A
Thailand	H013101	Nakhon Phanom	Mekong	5/15/85		A
Thailand	H013801	Khong Chiam	Mekong	5/15/85		A
Thailand	H050104	Chiang Rai	Mae Kok River	5/15/85		A
Thailand	H290102	Ban Tha Kok Daeng	Song Khram River	5/15/85	5/13/04	N
Thailand	H290103	Ban Chai Buri	Song Khram River	6/16/04		A
Thailand	H310102	Na Kae	Kam River	5/15/85		A
Thailand	H370104	Yasothon	Chi River	5/15/85	12/14/05	N
Thailand	H370115	Ban Kok	Chi River	5/15/85	5/18/04	N
Thailand	H370122	Ban Chot	Chi River	5/15/85	5/17/04	N
Thailand	H370299	Nam Pong Dam	Pong River	5/15/85	5/18/04	N
Thailand	H371203	Ban Tad Ton	Huai Pa Thao River	1/15/90	5/17/04	N
Thailand	H371499	Lam Pao Dam	Pao River	5/15/85	5/18/04	N
Thailand	H380103	Ubon	Mun River	5/15/85		A
Thailand	H380127	Kaeng Saphu Tai	Mun River	5/15/85	5/17/04	N
Thailand	H380128	Mun (Khong Chiam)	Mun River	6/15/04		A
Thailand	H380133	Ban Som	Mun River	1/15/90	5/17/04	N
Thailand	H380134	Rasi Salai	Mun River	5/15/85	12/14/05	N
Thailand	H380903	Ban Ku Phra Ko Na	Lam Seio Yai River	5/15/85	5/17/04	N
Thailand	H381699	Lam Dom Noi	Mun River	5/15/85	12/14/05	N
Viet Nam	H019803	Tan Chau	Mekong River	4/14/86		A
Viet Nam	H019804	My Thuan	Mekong River	12/14/86		A
Viet Nam	H019805	My Tho	Mekong River	4/14/86		A
Viet Nam	H029812	Dai Ngai	Bassac River	10/15/04	12/15/09	N
Viet Nam	H039801	Chau Doc	Bassac River	8/14/86		A
Viet Nam	H039803	Can Tho	Bassac River	6/14/86		A

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

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

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

In 2023, 19 water quality parameters were monitored by the WQMN (Section 2.3), but between 1995 and 2004, up to 23 water quality parameters were monitored. These parameters comprised physical, chemical and bacteriological parameters, and have been deemed 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 that will be decentralized to the MCs for full implementation. Following decentralization, 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 the national level, each MC 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, 2023

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 Subdivision, 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 the 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 and internal auditing to ensure consistency and integrity of the recorded data;
- manage water quality data in accordance with the agreed format and submit the data to the MRCS for validation and sharing through the MRC data portal; and
- produce and publish annual water quality data assessment report, outlining the results of water quality monitoring, analysis and assessment.

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

1.2.2 Procedures for Water Quality

Routine water quality monitoring within 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 jointly developed and adopted the Technical Guidelines for the Implementation of the Procedures for Water Quality (TGWQ), which consist of two main parts: Part I regarding the management of water quality, and Part II, establishing a framework for responding to water quality emergency incidents. Since its adoption, the implementation of Part I of the TGWQ has been through the implementation of the WQMN. Part I 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, which ensure the comparability of the monitoring data.

Chapters 1 and 2 aim to provide decision support tools *for the management by the Member Countries to maintain good/acceptable water quality of the Mekong mainstream*. Water quality criteria (indicators and target values) of key parameters were collaboratively adopted by the MCs to support them in maintaining good/acceptable water quality. In Chapter 1, water quality criteria are grouped into two types (Direct Impact Parameters and Indirect

Impact Parameters), depending on their characteristics and their potential effects on human health (Tables 1.3 and 1.4).

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

No.	Parameters	Symbol	Unit	Value	Analytical method[1]
1	Total arsenic	Total As	mg/l	0.01	3550-As/SM
2	Cadmium	Cd	mg/l	0.005[2]	3110-Cd/SM
3	Chromium hexavalent	Cr	mg/l	0.05	3550-Cr/SM
4	Cyanide	CN	mg/l	0.01	4500-CN/SM
5	Lead	Pb	mg/l	0.05	3110-Pb/SM
6	Total mercury	Total Hg	mg/l	0.002	3112-Hg/SM
7	Oil and grease	***Should not occur in such a way that:*** • It can be observed as an oil film, sheen or discolouration. • One can smell its odour, or • 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	1,000[3]	9221E-Fecal Coliform/SM

[1] If the laboratories rely on their own methods and/or non-standard methods, they must 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/100 ml	5,000	9221-Coliform group/SM

[1] If the laboratories use their in-house methods and/or non-standard methods, they must 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 in Chapter 2 are grouped into two types, i.e. direct impact parameters and environmental stressor parameters, because 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))

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

(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 within the WQMN has become one of the key environmental monitoring activities implemented by 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:

- Provide the status of water quality in the Mekong River in 2023 by assessing water quality monitoring data monitored by the WQMN laboratories in 2023 against the target values established by the TGWQ (Section 1.2.2).
- Conduct an exploratory analysis of any spatial changes observed in the Mekong River's water quality in 2023.
- 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 2023.
- Assess the suitability of the Mekong River's water quality for the protection of human health, the protection of aquatic life and/or support the productivity of the agricultural activities in the LMB.
- 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

In 2023, 48 stations were monitored by the WQMN. A breakdown of the number of stations in each MC is presented in Table 2.1. As can be seen in the table, 11 out of the 48 stations monitored in 2023 were located in Lao PDR, eight 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. It is important to note that the water quality of the 3S and Tonle Sap River Systems was monitored at five stations (three in Cambodia and two in Viet Nam) and six stations, respectively. For the Bassac River, water quality was monitored at five stations: three of these stations (Takhmao, Koh Khel and Koh Thom) are located on the Cambodia side of the river, and the other two stations (Chau Doc and Can Tho) are located on the Viet Nam side. For the Mun River System, two stations were established to provide historical records of the 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 2023 and historically at one station each (Table 2.2 and Figure 2.1).

This report provides the analyses of water quality conditions including status and trends, at all 48 mainstream and tributary stations. Here, the names of these stations have been abbreviated, as listed in Table 2.2, and their spatial locations are shown in Figure 2.1.

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

Table 2.1. A summary of 2023 water quality monitoring stations

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

Table 2.2. The 48 stations that monitor water quality, 2023

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

Station abbr.	WQMN station ID	Station name	River name	Country	Latitude	Longitude
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

Denotes mainstream stations

Denotes other tributary stations including those located in the Bassac, 3S, and Tonle Sap Basins

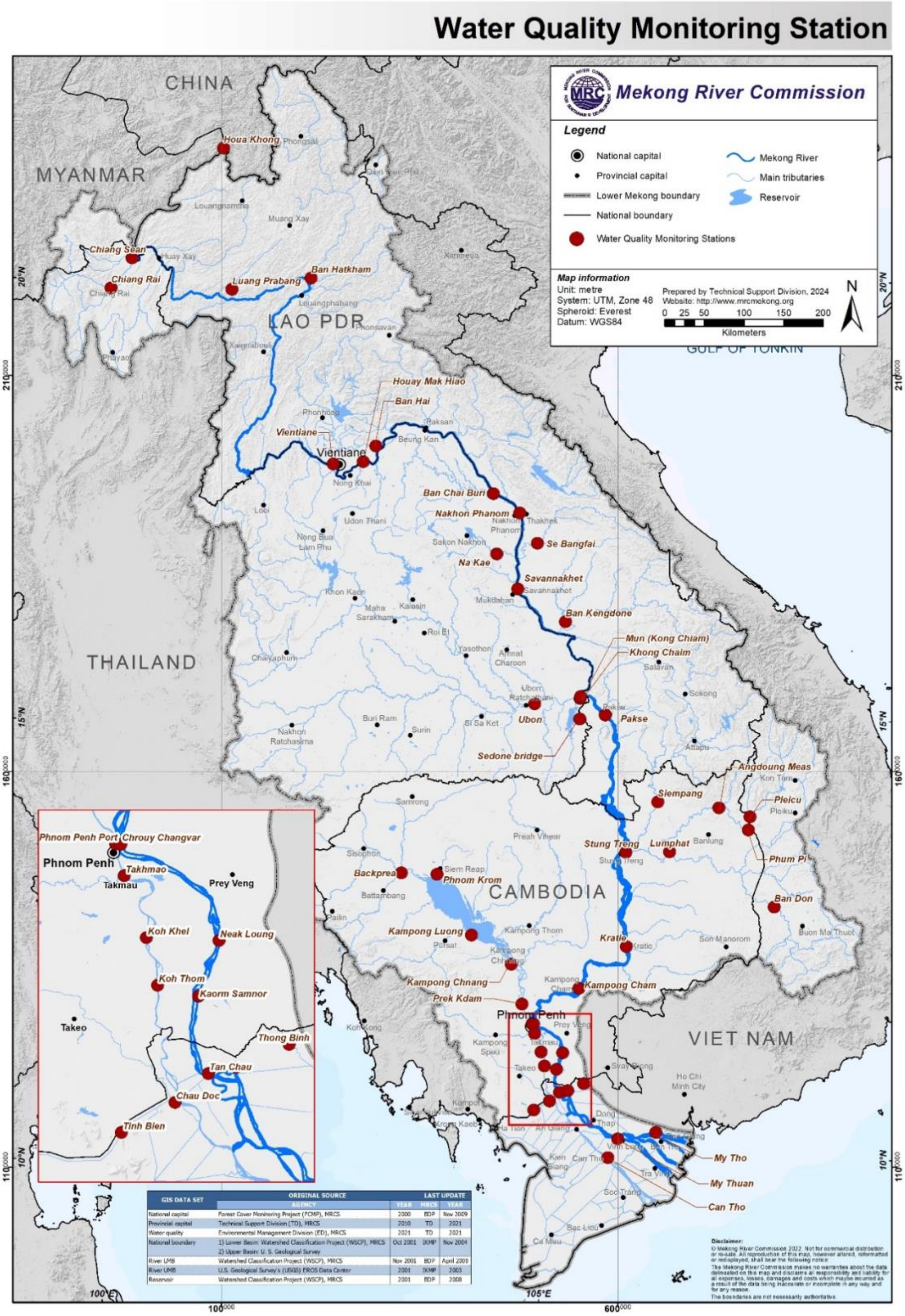

Figure 2.1. Spatial distribution of the 48 primary water quality stations monitored by the WQMN, 2023

2.2 SAMPLING TECHNIQUES

In order to standardize the sampling techniques, in 2023, the 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 2023, water quality sampling and sample preservation, transportation and storage would be carried out in accordance with methods listed in the Technical Guidelines for the Procedures for Water Quality (TGWQ) (Section 1.2.2) or with national standards complying with the requirements of method validation of ISO/IEC 17025-2005. It should be noted that the TGWQ were prepared in accordance with the 23rd edition of the Standard Methods for the Examination of Water and Wastewater (Baird, 2017).

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 30–50 cm under the surface of the stream;
- if in-situ measurement is not possible, immediately preserve samples collected with appropriate preservative agents (i.e. sulphuric acid for nutrients measurement) and store them 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 17025-2017 and personnel safety procedures when collecting water samples and measuring water quality parameters.

2.3 LABORATORY ANALYTICAL METHODS

Since its inception in 1985, the MRC WQMN has provided data on water quality in the Mekong River and its selected tributaries by measuring a number of different water quality parameters. At its peak performance, it was capable of measuring 23 water quality parameters, but in 2023, only 19 water quality parameters were measured (Table 2.3). Twelve of these parameters were considered routine water quality parameters that must be measured each monitoring month; the other six – major anions and major cations – must be analysed monthly for each sample taken between May and October.

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

Table 2.3. Water quality parameters and their corresponding analytical methods

Analytical parameter	MRC WQMN Recommended analytical methods[1]	Frequencies
Temperature	2550-Temp/SM	Monthly
pH	4500-H^+/SM	Monthly
Electrical conductivity (EC)	2510-EC/SM	Monthly
Alkalinity/acidity	2320-A/SM	Monthly
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	Lao PDR: April – October Viet Nam: March, April, August and September. Thailand: Monthly Cambodia: Monthly (except Na and K)
Magnesium (Mg)	3500-Mg-B/SM	
Sodium (Na)	3500-Na-B/SM	
Potassium (K)	3500-K-B/SM	
Sulphate (SO_4)	4500- SO_4–E/SM	
Chloride (Cl)	4500-Cl/SM	
Biochemical oxygen demand (BOD_5)	5210-BOD_5/SM	Monthly

2.4 WATER QUALITY DATA ASSESSMENT

In order to analyse 2023 water quality data, it is necessary to collate and validate water quality data collected at the national level by the MCs. After the successful validation of these national databases, it was possible to aggregate them into the regional water quality database, which facilitated a basin-wide analysis of water quality status and trends. Figure 2.2 illustrates the approach used for water quality data analysis to support this regional water quality data assessment report. It highlights four key types of data analyses, consisting in: the assessment of water quality status in 2023; the spatial of assessment of changes in 2023; the temporal assessment of changes; and the exploratory analysis of potential transboundary water quality issues. The methodology and approach used for these analyses are discussed in detail in Sections 2.4.1 to 2.4.4, and are summarized as follows:

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

- an ev/aluation of the status of the Mekong River's water quality recorded in 2023 (Section 2.4.1), compared to MRC water quality thresholds as listed in Chapter 1, Guidelines for the Protection of Human Health (Table 1.3) and Chapter 2, Guidelines for the Protection of Aquatic Life (Table 1.4);
- explorative analyses of the spatial variation of the water quality along the Mekong River mainstream using a variety of proven statistical techniques, as discussed in section 2.4.2 of this report;
- an assessment of temporal variation of key water quality indicators at all 48 stations monitored in 2023 using a variety proven statistical techniques, as discussed in Section 2.4.3; and
- an explorative analysis of, and a discussion on, the potential transboundary water quality issues among stations that have been strategically established to detect the conditions of water quality entering and leaving national boundaries of the MCs (2.4.4).

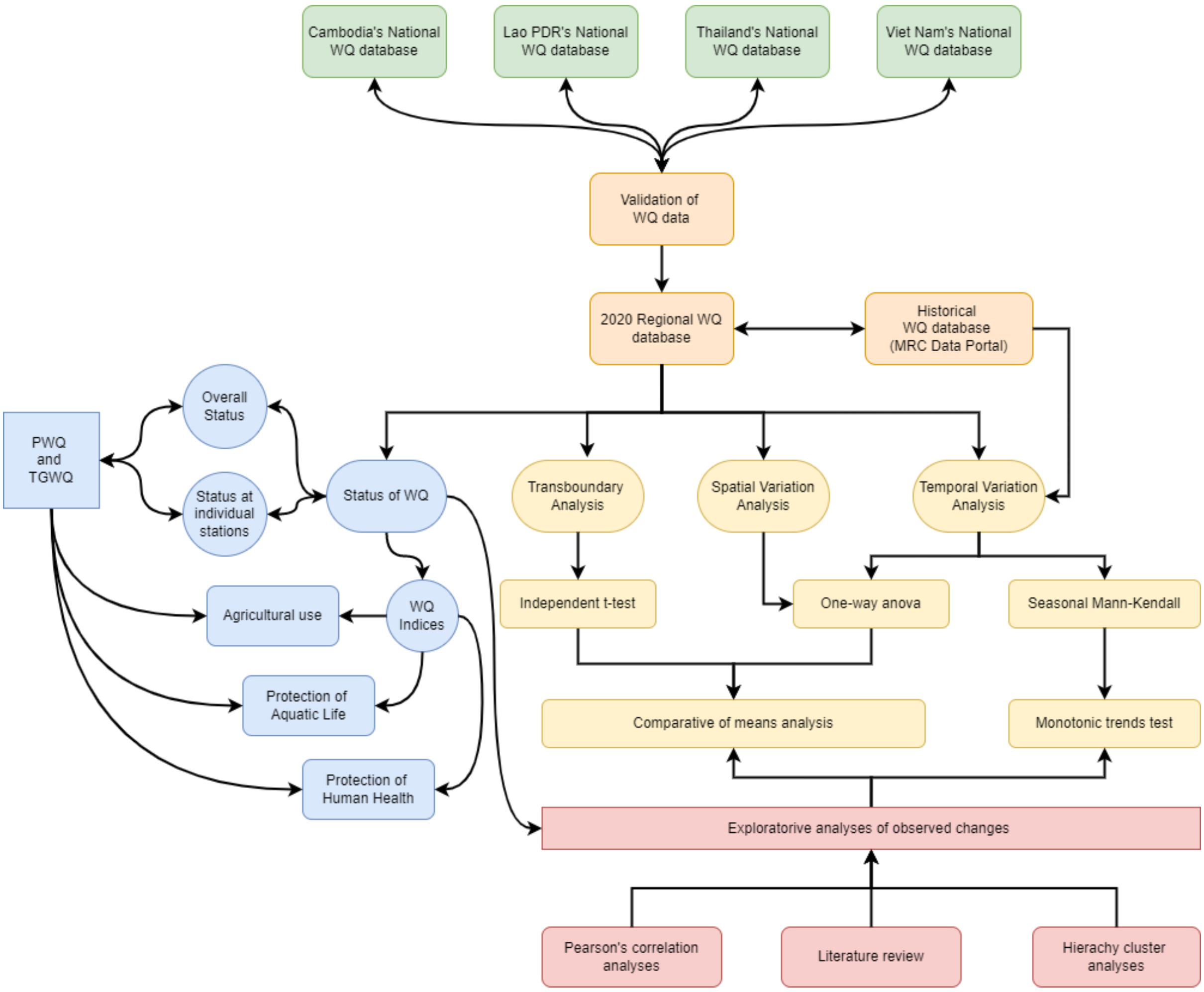

Figure 2.2. The approaches used for the analyses of 2023 water quality data to support the identification of water quality status and spatio-temporal variation

2.4.1 Assessment of Water Quality Status

2.4.1.1 Descriptive Statistical Analysis

The overall status of the water quality of the Mekong in 2023 was examined by applying descriptive statistics, such as annual maximum, mean and minimum to summarize data series of key water quality parameters collected in 2023 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), because they provide quick snapshots of data series that are generally large and not event-distributed. These values were compared to the water quality thresholds of the MRC WQGH (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 Tables 1.3 and 1.4). 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 WQIs (section 2.4.1.2, Tables 2.4, 2.6 and 2.8). Any exceedance and/or non-compliance observed in any key water quality parameters were further characterized at an individual station level (Table 2.2) through another assessment of descriptive statistical analysis. 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 WQIs. In addition, the proportions of data points that exceeded or violated water quality thresholds were also determined to quantify the extent or scale of water quality issues.

As illustrated in Figure 2.2, the assessment results of the water quality status serve as one of the key data to support the statistical analyses for determining 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 carried out through the utilization of previously adopted MRC WQIs. In 2013, the MCs adopted three indices taking into account the requirements of the PWQ and its TGWQ (Section 1.2.2), as follows:

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

2.4.1.2.1 Water Quality Index for the Protection of Aquatic Life

The Water Quality Index for the Protection of Aquatic Life (WQI_{al}) is calculated using **Equation 2.1**. It has been developed as an open-ended index, which would allow more parameters to be added once data become available (Campbell, 2014). In this annual water quality report, only six parameters are included, which, 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 number of 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 and their target values

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

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

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

2.4.1.2.2 Water Quality Index for the Protection of Human Health

With the finalization of **Chapter 1,** Guidelines for the Protection of Human Health (HH), of the Technical Guidelines for the Implementation of the Procedures for Water Quality, the MCs 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, MCs 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 Index is summarized in Table 2.7.

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

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

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

F_2 is the percentage of individual tests for each parameter that exceed the guidelines and can be calculated using **Equation 2.4**.

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

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

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

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

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

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

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

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

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

Note: *Due to the required holding time for BOD, the MCs have agreed to only monitor BOD at stations where samples can be analysed within the required holding time of less than 48 hours. Therefore, BOD was only included for the stations where data are 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 most 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 MCs as a means for communicating water quality monitoring information to the public is the Water Quality Index for Agricultural Use, which focuses on water quality for general and paddy rice irrigation. The indices for general and paddy rice irrigation are outlined in Table 2.8.

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

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

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

2.4.2 Assessment of Spatial Variations

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

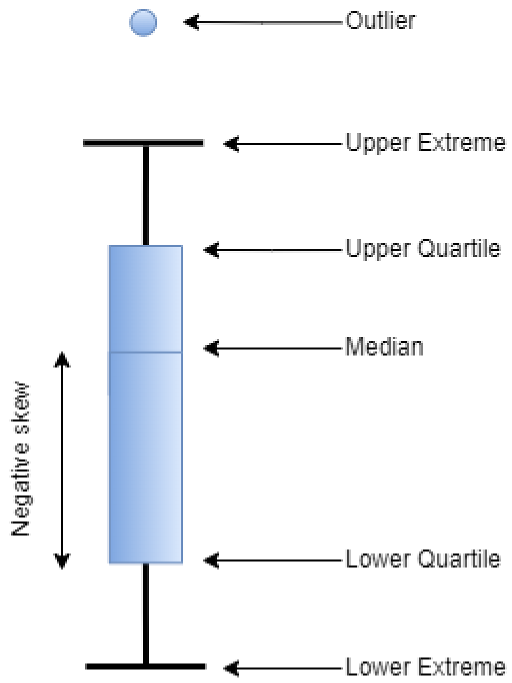

Figure 2.3. Information visualized by box-and-whisker plot

The box-and-whisker plot (DuToit et al., 2012; Thompson, 1992) was used to visualize the distribution of 2023 water quality data for key parameters. Although water quality data can be illustrated in multiple different ways by using a box-and-whisker plot, it is a non-parametric statistical method and has often been used to support the analysis of non-normal distribution data. These data include environmental monitoring data, such as water quality data, which are highly susceptible to the influences of seasonality and surrounding natural and anthropogenic factors (Larsen, 1985; Ly & Metternicht, 2020; Thirumalai, Vignesh & Balaji, 2017). Using the box-and-whisker plot, key elements of the dataset can be easily extracted, such as information on the minimum, maximum and median, and the first and third quartile of the dataset (Larsen, 1985). Therefore, this 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 range of data visualization (Statistics Canada, 2021). Additionally, the box-and-whisker plot can provide valuable information on the distribution of the dataset through its visualization of the skewness of data, which can be used to support the identification of appropriate statistical analysis techniques and/or data pre-treatments (Boddy & Gordon, 2009). For this regional report, to illustrate the water quality data, a box-and-whisker plot was generated using the 29th Version of IBM SPSS Statistical Software (IBM Corp., 2023).

The use of a box-and-whisker plot for the spatial variation assessment of the 2023 water quality data along the 17 mainstream stations was supported 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 2023, 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, the one-way ANOVA test is commonly used to determine whether the observed differences in the means of three or more independent datasets (e.g. datasets 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, the one-way ANOVA test was used to compare the mean values of key water quality parameters of the 17 mainstream stations. Accordingly, this tested the validity of a null hypothesis, as detailed in Equation 2.8.

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

Where,

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

Should the one-way ANOVA test return a statistical significant result (Equation 2.8), an alternative hypothesis (H_A) would be accepted, indicating that the mean concentration of the water quality parameter of at least two stations is statistically significant (Heiberger & Neuwirth, 2009; Kim, 2017). For this regional report, the one-way ANOVA test was used together with the test of normality, with non-normal distributed data 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 explain the variation observed. In statistic and data sciences, Pearson's correction coefficient (also known as 'Pearson's r') is used to measure the linear correlation between two or more datasets (Benesty et al., 2009;

Connolly et al., 2015; Ly & Metternicht, 2020). Accordingly, 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.)[2] and the product of their standard deviations (Benesty et al., 2009).

When applying to datasets, Pearson's correlation coefficient can be estimated by Equation 2.9 (ibid.), as follows:

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

Where,

r_{xy} is the Pearson's correlation coefficient of the two datasets (x and y) being tested;

x_i and y_i are individual concentrations of the two water quality parameters monitored at time i; and

$\bar{x}$ and $\bar{y}$ are the mean concentration of dataset x and y, respectively.

In addition to Pearson's correlation, this regional report utilizes previously published literature and/or scientific research 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

In the 2023 Regional Water Quality Data Assessment Report continued to assess temporal variations at the station level, with all temporal changes in key water quality parameters examined at 17 stations in the main stream. At many of these stations, historical data dated back to 1985. Therefore, all available records of water quality data were used for temporal assessment, covering the 1985–2023 period for many stations. Similar to the assessment of spatial variations (Section 2.4.2), a combination of graphical visualizations and statistical analyses was applied to the historical record of key water quality parameter, allowing for the detection and assertion of any temporal changes.

A cluster bar chart was used to illustrate changes in mean annual concentrations of key water quality parameters. In addition, the changes in monthly concentrations of key water quality parameters and their monotonic trends were assessed by the seasonal Mann-Kendall test (Hirsch, Slack & Smith, 1982; Ly & Metternicht, 2020). Known as a non-parametric statistical method, the seasonal Mann-Kendall test has been well utilized in environmental monitoring and assessment due to its flexibility and suitability for non-normal distributed datasets that are susceptible to seasonal influences (Ly & Metternicht, 2020; von Sperling et al., 2020). Proposed by Hirsch, Slack and Smith (1982) as a seasonal modification to the Mann-Kendall test (Al-Mashagbah & Al-Farajat, 2013). The following null and alternative hypotheses were tested using the seasonal Mann-Kendall test:

[2] For example, [pH]:[NO32] denotes a ratio of pH dataset to that of NO3-2.

H_0 = There is 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 computes the Z_{SK} statistic value of the datasets as per Equations 2.10 to 2.12 (Hirsch, Slack & Smith, 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 Mann-Kendall test statistic and is the sum of the difference between all of the combinations observed, while the VAR(S') is its variance. Hirsch, Slack & Smith (1982) provide a detailed step-by-step approach to how these statistics can be calculated. For 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 python code.

To explain the observed statistically significant changes in monotonic trend, the seasonal Mann-Kendall test was applied. Specifically, these explanations include the use of Pearson's correlation coefficients supplemented by previously published studies and/or research journals.

2.4.4 Exploration of Potential Transboundary Water Quality issues

The MRC's Technical Paper No. 19 (2008) identified five main transboundary areas along the Mekong River for assessing transboundary water quality in the Mekong and Bassac Rivers, as follows:

1. **People's Republic of China/Lao PDR** — A water quality monitoring station was established in Houa Khong (LHK) in 2004 to monitor the boundary between the Upper and Lower Mekong Basin.
2. **Lao PDR/Myanmar** — There is no water quality station in this part of the river since it is remote and sparsely populated.
3. **Thailand/Lao PDR** — There are many monitoring stations along this stretch of the Mekong River, including stations 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, in the past, Pakse (LPS) and Stung Treng (CST) monitoring stations were considered transboundary stations. However, due to the long distance between the two stations (about 200 km), the potential transboundary issues may not reflected by key monitoring parameters.
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 not located far from the Cambodian/Vietnamese border. Similarly, Koh Thom station (CKT) in Cambodia, and Chau Doc station (VCD) in Viet Nam, which are located on the Bassac River, can be considered transboundary stations due to their proximity to the Cambodian/Vietnamese border.

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

In exploring potential transboundary water quality issues among the identified transboundary stations, this 2023 water quality report utilizes both graphical visualization and statistical exploratory analysis to ascertain the difference in the levels of key water quality parameters monitored at these stations. Specifically, the water quality datasets from these stations were visualized by using the box-and-whisker plot (Section 2.4.2 and Figure 2.3).

Statistically, the two-sample t-test (Fu & Wang, 2012; Gerald, 2018; von Sperling et al., 2020; Wilcox, 1990) was applied to determine whether there was a statistically significant difference between the mean concentrations of key water quality parameters of the two transboundary stations. In statistic and data science, the t-test allows to compare the average values of two datasets by determining their statistical significance through the computation of their t-statistic, t-distribution and the degree of freedom. Wilcox (1990) provides a detailed discussion on, and step-by-step approach to, the computation of the statistics, but here, the two sample t-test was used to test whether a null hypothesis (H_0), i.e. the mean concentration of water quality parameters at two stations were equal (Equation 2.13), can be rejected. Should the t-test return statistically significant results at the 0.05 level, an alternative hypothesis (H_A) 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, μ_1 and μ_2 denote the average concentrations of a water quality parameter at stations 1 and 2, respectively. For this report, the sample t-test analysis was carried by using the 28th Version of IBM SPSS Statistical Software (Version 29).

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

2.5 QUALITY ASSURANCE / QUALITY CONTROL

Recognizing the need to improve the quality, precision and accuracy of the water quality data, all designated laboratories of the MRC WQMN were requested to participate in the implementation of a quality assurance and quality control (QA/QC) test for water sampling, and sample 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 17025–2017. To date, of the four designated laboratories of the MRC WQMN, the laboratories in Lao PDR has received ISO/IEC 17025-2017 certification. The certifications were granted by the Bureau of Laboratory Accreditation, Department of Science Service.

Other designated laboratories, although not ISO/IEC 17025-2017-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 17025-2017. The MRC QA/QC procedure calls for the designated laboratories to:

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

3. RESULTS

3.1 STATUS OF THE MEKONG WATER QUALITY IN 2023

In 2023, 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 3,294 data points for the 17 stations located in the Mekong mainstream; 951 data points for the five Bassac River stations; and 4,965 data points for the 26 tributary stations, in Lao PDR's tributaries (six stations, 1,141 data points), Thailand's tributaries (five stations, 1,100 data points), 3S (six stations, 1,080 data points), Tonle Sap tributary (six stations, 1,104 data points) and Viet Nam's Delta (three stations, 540 data points). The 2023 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 "good/acceptable". Specifically, the data of key water quality parameters were compared against their respective target values adopted by the MCs 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 along the Mekong River (Table 3.1 and Annex A) and tributaries (Table 3.2). As with other types of environmental monitoring time series data, water quality time series data of the MRC WQMN are 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 rated as "good/acceptable" against the established target values (Fu & Wang, 2012; von Sperling et al., 2020). The status of water quality in the Mekong mainstream and its tributaries in 2023 is discussed separately in Sections 3.1.1 and 3.1.2.

3.1.1 Mekong Water Quality in 2023

The results of descriptive statistical analyses of the water quality data from 17 Mekong mainstream stations (Section 2.1 and Table 2.2) reveal that water quality of the Mekong River in 2023 was generally of moderately good quality. There were six water quality parameters, i.e. pH, electrical conductivity (EC), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD) and faecal coliform (FC), that were observed in at least one sample out of the target values of WQGH and WQGA. Of the remaining five parameters (TSS, NO_{3-2}, NH4, TOTN and TOTP) used as proxies for water quality in this report, data NO_{3-2} were well within their target values of WQGH (at all 17 stations) (Table 3.1).

Of the six water quality parameters with one or more data points exceeding their respective target values of WQGH and WQGA, EC values had most data points lower than 70 mS/m; only one data point at My Tho (VMT) stations (78.2 mS/m in March 2023) belonged to the recommended target range of 70 – 150 mS/m of the WQGH. The lowest EC (11.7 mS/m) was recorded at Kratie station (CKR) in September 2023, and the highest EC (78.3 mS/m) at VMT in March 2023 (Annex A). Although the EC was high in March 2023 at VTM, the mean EC at this station was not much higher than in 2022, i.e. at 29.63 mS/m in 2023 compared to 24.71 mS/m in 2022.

In 2023, FC continued to impair the water quality of the Mekong River. Nearly 31% of FC samples (51/165) exceeded the WQGH target value (1,000 MPN/100 ml), which slightly decreased compared to 2022 water quality data (34% or 57/168 FC samples). The FC values were exceeded at the following stations: Kampong Cham (CKC, 11/12 months), Chroy Chanvar (CCC, 12/12 months), Neak Loeung (CNL, 12/12 months), Chiang Saen (TCS, 6/12 months), Nakhon Phanom (TNP, 3/12 months), Khong Chiam (1/12 months), My Tho (VMT, 4/12 months) and Tan Chau (VTC, 2/12 months). The highest FC value was recorded at VMT in January 2023, at 150,000 MPN/100 ml. Since VMT is located next to the port, where human activities are intensive, pollution from anthropogenic sources should be take into account in the abnormally high FC values. For all the mainstream stations, the average of FC in the maistream was 2,254 MPN/100 ml. FC impairment of the Mekong River water quality was expected given the current sanitation situations in the LMB, with the open defecation rate remaining high among the rural population of the MCs, at 80% in Cambodia and 24% in Lao PDR (UNICEF Cambodia, 2019; UNICEF Lao PDR, 2019).

COD and BOD values ranged from 0.38 mg/L to 6.61 mg/L and 0.49 mg/L to 4.19 mg/L, respectively. Exceeded threshold values of WQGH (5 mg/L) were recorded for COD at Houa Khong (LHK) in January, at Pakse (LPK) in April, at Chiang Saen (TCS) in May, VMT in February, June and August, at My Thuan (VHM) in September, November and December, and at Tan Chau (VTC) in October and December. The highest COD was recorded at TCS. The values recorded at the other stations were below the target value of WQGH (5 mg/L). The average value of COD in the mainstream was below the WQGH, at 2.57 mg/L. The average concentration of COD was lower in 2023 (2.57 mg/L) than in 2022 (2.67 mg/L), i.e. the water quality with respect to COD slightly improved in 2023. The average BOD of the mainstream stations was also below the WQGH (4 mg/L) and WQGA (3 mg/L), at 1.21 mg/L. This value is the same as in 2022.

With regard to DO, 6% of water samples were below the target values of WQGH (6 mg/L). Compared to 2022, The DO values that did not meet the target values of WQGH (6 mg/L) significantly decreased from 19.1% to 6% of the samples. In addition, all DO values are well above the target value of WQGA (5 mg/L). This reflects the improvement of water in the mainstream according to the DO. The improvement is clearly shown in the data of VMT, where the average DO values increased from 5.05 mg/L in 2022 to 6.63 mg/L in 2023.

The pH was lower than the low target value of WQGH and WQGA (6) at VMT in April. The highest pH was recorded at Vientiane station (LVT) in January, at 8.42. In comparison to 2022, the pH in the mainstream was stable and slightly higher, at 7.40 in 2023 compared to 7.33 in 2022.

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

Periods	Seasonal	Statistical Parameters	pH	TSS (mg/L)	EC (mS/m)	NO_{3-2} (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100mL)	BOD (mg/L)
TGWQ	**Chapter 1 (WQGH)**		6–9	-	70 - 150	5.00	-	-	-	≥ 6	5.00	1,000	4.00
	Chapter 2 (WQGA)		6–9	-	-	5.00	-	-	-	5.00	-		3.00
2023	Dry season	Mean	7.27	18.62	26.27	0.24	0.05	0.47	0.06	7.17	2.45	3,746	1.48
	Wet season	Mean	7.28	73.74	21.58	0.34	0.07	0.57	0.15	6.88	3.02	2,475	1.55
	Total	Max	8.42	457.40	78.30	2.19	0.90	2.40	0.99	8.94	6.61	150,000	4.19
		Mean	7.33	49.46	24.78	0.23	0.06	0.40	0.11	7.08	2.57	2,254	1.21
		Min	5.87	2.80	11.70	0.01	0.00	0.05	0.01	5.04	0.38	BDL	0.49
		St. dev.	0.44	63.34	7.92	0.22	0.08	0.34	0.10	0.68	1.67	11,763	0.86
2022	Dry season	Mean	7.47	26.15	25.57	0.16	0.04	0.37	0.06	6.96	2.37	6,435	1.19
	Wet season	Mean	7.33	90.27	22.23	0.18	0.04	0.43	0.09	6.71	2.97	2,740,235	1.24
	Total	Max	8.64	785.00	55.40	1.28	0.35	2.37	0.33	8.85	7.73	230,000,000*	7.47
		Mean	7.40	58.21	23.90	0.17	0.04	0.40	0.07	6.83	2.67	5,476*	1.21
		Min	6.05	3.50	9.70	0.01	0.00	0.07	0.01	4.32	0.25	BDL	0.00

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	5.00	-	-	-	≥ 6	5.00	1,000	4.00
	Chapter 2 (WQGA)		6–9	-	-	5.00	-	-	-	5.00	-		3.00
		St. dev.	0.45	73.85	8.08	0.20	0.04	0.42	0.05	0.93	1.69	19,089*	0.96
Historical	Total	Max	9.94	5716	841	2.19	2.99	4.89	2.20	13.85	65	240,000	7.47
		Mean	7.48	129.58	21.45	0.25	0.05	0.57	0.09	7.16	2.29	128,666	1.23
		Min	3.78	0.10	1.20	0.00	0.00	0.00	0.00	0.00	0.00	BDL	0.00
		St. dev.	0.50	234.17	28.54	0.10	0.10	0.40	0.11	1.08	1.90	5,322,898	0.94

Note: * Blue indicates non-compliance with WQGH or WQGA. BLD: below limit detection.
** The highest value is excluded for the calculation of mean and standard deviation.

3.1.2 Water Quality of Key Tributaries in 2023

Table 3.2 provides a descriptive statistical summary of key water quality parameters of the Mekong River tributaries in 2023. For this report, the stations of the tributaries of the Mekong River are grouped as follows:

- Five Bassac River stations monitored by the designated laboratories of Cambodia and Viet Nam (Table 1.1), with results summarized in Table 3.2;
- Six tributary stations monitored by the designated national laboratory of Lao PDR (Table 1.1), with results summarized in Table 3.2;
- Five tributary stations monitored by the designated national laboratory of Thailand (Table 1.1), with results summarized in Table 3.2;
- Five tributary stations located in the 3S River System as monitored by the designated national laboratories of Cambodia and Viet Nam (Table 1.1), with results summarized in Table 3.2;
- Six tributary stations located in the Tonle Sap River System, including those located in the Tonle Sap Lake, as monitored by the designated laboratory of Cambodia (Table 1.1), with results summarized in Table 3.2; and
- Viet Nam's Delta three canal stations, which were monitored by the designated laboratories of Viet Nam (Table 1.1), with results summarized in Table 3.2.

In 2023, water quality of main tributaries was similar to that of the mainstream of the Mekong River, except for pH. In the tributaries, all pH values were in the range of the target values of WQGA and WQGH (6–9, Table 3.2). Together with pH, the NO3-2 concentrations were also low and below the threshold value of 5 mg/L for WQGA and WQGH. The EC was below the lower limit of WQGH (70–150 mS/m), except for the EC at LHM, a tributary station in Lao PDR. At LHM, the EC was lower than the minimum target value of WQGH (70–150 mS/m) from June to September 2023, and was in the target range in the remaining months. The highest mean EC was at Lao PDR's tributaries (31.4 mS/m). The mean EC values at the other tributaries were as follows: 3S River System, Tonle Sap River System, Bassac River, Thailand's tributaries, and Viet Nam's Canal, at 6.8, 13.9, 18.4, 19.8 and 21.5, respectively. The lowest EC value was 4.37 mS/m in October at VPC (3S Basin), and the highest EC was 124.6 mS/m in February at LHM (Lao PDR tributaries).

The FC value ranged from 3 to 32,000 MPN/100 ml. The highest FC value was 32,000 MPN/100 ml, detected in November at Takmao (CTK, a station along the Bassac River System in Cambodia). The percentages of samples that exceeded the WQGH (1,000 MPN/100 ml) in Thailand's tributaries, Bassac River and Viet Nam's Delta were 25.5% (14/55), 52.1% (25/48) and 11% (4/36), respectively. At CPP, which is the station monitoring FC in the Tonle Sap River System, all the samples exceeded the target value of WQGH. It should be noted that CPP is located close to Phnom Penh Port; hence, the exceedance of FC values was mainly related to pollution from human activities. However, no sample showed the exceedance of Fe according to the target value of the WQGH in the 3S River System and Lao PDR's tributaries. In Thailand's tributaries, exceeded FC values were occasionally observed at TCR (5/12 samples), TNK (2/12 samples), TUB (5/12 samples) and TMK (2/12 samples). The exceeded FC values ranged from 1,100 MPN/100 ml to 16,000 MPN/100 ml, and the highest values was at TCR (16,000 MNP/100 mL). In the Bassac River System, two stations in Cambodia (CTK and CKT) recorded

FC values above the WQGH (1,000 MPN/100 ml) at all data points, ranging from 3,900 MPN/100 ml to 32,000 MPN/100 ml. For Bassac River stations in Viet Nam, exceeding FC values were detected only once, in January 2023 at VCT (24,000 MNP/100 ml). In Viet Nam's Delta, all three stations sometimes recorded a FC value higher than WQGH (1,000 MPN/100 ml), ranging between 1,400 MPN/100 ml and 24,000 MPN/100 ml.

For COD, the highest concentration was 7.21 mg/L in August at LHM, a station of Lao PDR's tributaries. At this station, 41.7% (5/12 samples) of the samples exceeded the WQGH target value (5 mg/L). The mean COD concentrates in the tributaries were 1.71, 2.26, 3.51, 3.72, 4.52, and 5.11. respectively, in 3S, Tonle Sap, Lao PDR's, and Thailand's tributaries and Viet Nam's Canal.

In contrast to COD concentrations, BOD concentrations indicated "good" water quality in the tributaries. Regarding the targe value of the WQGH (4 mg/L), all BOD samples were well below this threshold. However, 4.8% of total BOD samples (9/186) in tributaries exceeded the threshold values of WQGA (3 mg/L). This result indicates that the water quality slightly declined compared to 2022 (2.4%) in term of BOD.

Regarding DO, water samples sporadically showed values lower than the target value of WQGH (6 mg/L) at all tributaries, with 19% of samples. With regard to WQGA (5 mg/L), 4.6% of samples had DO values lower than 5 mg/L, which was recorded in Lao PDR's tributaries, Thailand's tributaries, Bassac River System and Viet Nam's Delta. Similar to the DO of the Mekong River mainstream, the DO with respect to the target values of WQGH (6 mg/L) and WQGA (5 mg/L) in the tributaries also showed an improvement in comparison to the data in 2022. Specifically, the DO lower than 6 mg/L was reduced in 32.8% of DO samples in 2022 to 18.8% of DO samples in 2023. For the percentage of DO lower than 5 mg/L, it was reduced from 5.6% in 2022 to 4.6% in 2023. In particular, the DO was significantly restored to better conditions in the stations in Bassac River System and Viet Nam's Delta, where 28 DO samples were lower than 6 mg/L in 2023 compared 57 samples in 2022.

Table 3.2. Water quality status of key tributaries of the Mekong River in 2023

Periods	Statistical Parameters	pH	TSS (mg/L)	EC (mS/m)	NO_{3-2} (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ	**Chapter 1 (WQGH)**	6–9	-	70–150	5	-	-	-	≥ 6	5	1 000	4
	Chapter 2 (WQGA)	6–9	-	-	5	-	-	-	5	-		3
Lao PDR's Tributaries	Max	7.95	365	124.60	1.80	0.10	3.24	0.19	7.42	7.25	880	4.15
	Mean	7.22	52	31.40	0.29	0.02	0.54	0.06	6.08	3.72	193	2.04
	Min	6.09	1	7.58	0.05	0.01	0.11	0.02	2.08	0.61	20	0.10
	Std. deviation	0.37	76	28.13	0.39	0.02	0.80	0.03	1.05	1.27	165	0.90
Thailand's Tributaries	Max	7.91	216	62.10	0.55	0.17	1.13	0.19	9.45	9.49	16,000	3.09
	Mean	7.17	30	19.76	0.20	0.05	0.48	0.06	6.46	4.53	1,090	1.41
	Min	6.50	1	6.10	0.00	0.00	0.13	0.01	2.70	1.72	18	0.10
	Std. deviation	0.35	45	10.55	0.15	0.04	0.26	0.04	1.28	1.75	2,443	0.68
3S River System	Max	8.24	238	12.90	1.22	0.32	1.52	0.35	8.20	7.03	700	2.31
	Mean	7.16	41	6.79	0.24	0.07	0.41	0.11	7.24	1.71	53	1.97
	Min	6.22	2	4.37	0.02	0.00	0.05	0.01	5.01	0.35	3	1.58
	Std. deviation	0.45	54	1.63	0.26	0.08	0.35	0.09	0.55	1.66	146	0.20
Tonle Sap River System	Max	7.80	1051	26.7	0.39	0.34	0.77	0.65	7.70	4.76	11,000	1.45
	Mean	7.32	123	13.9	0.20	0.20	0.43	0.29	6.94	2.27	4958	1.03
	Min	6.88	8	11.0	0.06	0.06	0.14	0.07	5.60	0.80	2,200	0.65
	Std. deviation	0.24	175	3.07	0.08	0.07	0.16	0.14	0.51	1.08	2,538	0.27
Bassac River System	Maximum	7.70	165	31.30	1.08	0.42	3.50	0.90	7.80	6.02	32,000	3.43
	Mean	7.11	40	18.39	0.38	0.17	0.79	0.30	6.60	3.52	6,883	2.27
	Minimum	6.15	8	9.80	0.06	0.00	0.18	0.04	4.97	0.85	70	0.75
	Std. deviation	0.34	39	6.57	0.21	0.13	0.48	0.19	0.71	1.38	8,805	0.64

Periods	Statistical Parameters	pH	TSS (mg/L)	EC (mS/m)	NO_{3-2} (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ	**Chapter 1 (WQGH)**	6–9	-	70–150	5	-	-	-	≥ 6	5	1 000	4
	Chapter 2 (WQGA)	6–9	-	-	5	-	-	-	5	-		3
Viet Nam's Delta	Max	7.41	44	39.40	2.15	1.43	3.86	0.47	7.48	6.90	24,000	2.94
	Mean	6.80	27	21.48	0.59	0.15	1.19	0.16	6.23	5.11	1,375	2.19
	Min	6.25	7	10.40	0.03	0.00	0.33	0.03	5.12	4.13	3	1.67
	Std. deviation	0.30	11	8.42	0.51	0.30	0.84	0.12	0.64	0.82	4,213	0.26

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

3.2 CORRELATION OF KEY WATER QUALTY INDICATORS

The correlation between key water quality parameters monitored in 2023 have been established for the Mekong River mainstream and its main tributaries (Tables 3.3a, b). This is important to understand the instream behaviours of key water quality parameters (Lee et al., 2016; Ly & Metternicht, 2020).

The results of the Pearson's correlation indicated that DO was only negatively correlated with TOTN, with a significant P-value of 0.05. This suggests that TOTN is the only parameter that reflects the impact on the DO values in the mainstream in 2023; i.e. the improvement of DO values in 2023 was related to the lower influence of nutrient parameters (NO3-2, NH4-N, TOTN and TOTP), COD and BOD in the mainstream. In contrast, in the tributaries, the inputs of nutrient parameters (NO3-2 and TOTN), COD and BOD are still the main cause of low DO values, indicated by the negative correlation of DO with NO3-2, TOTN, COD, and BOD (significant P – value of 0.01).

TSS significantly showed negative correlation with EC and a positive correlation with NH_4N and TOTP in the mainstream and tributaries. This result explains the high TSS normally observed in the wet season and the month right after the wet season, which the run-off associated with pollutants discharges to the mainstream and its tributaries. More specifically, river water is diluted by rainwater during the wet season, resulting in lower EC, while high water flow and run-off discharge to the river causes an increase of TSS, NH_4N, TOTP and COD.

Furthermore, pH value was negatively correlated with NO3-2, NH_4N, TOTN, COD and BOD (Table 3.3a). These significant correlations can be explained by the fact that the occurrence of high nutrients, COD and BOD increases CO_2 concentrations and lowers the pH in water.

Regarding FC, the parameter significantly showed a positive correlation with NH4N and TOTP. This correlation may be an indicator of anthropogenic activities as sources of NH4N and TOPT in water in the mainstream and its tributaries.

Table 3.3. Correlation between key water quality parameters in the Mekong River, as monitored by the WQMN, 2023

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	1										
TSS (mg/L)	-.037	1									
EC (mS/m)	.054	-.298**	1								
NO_{3-2} (mg/L)	-.229**	.059	.198**	1							
NH_4N (mg/L)	-.236**	.216**	-.281**	.009	1						
TOTN (mg/L)	-.370**	.026	.100	.795**	.105	1					
TOTP (mg/L)	-.122	.330**	-.355**	-.052	.372**	-.008	1				
DO (mg/L)	.115	-.068	.046	-.110	.011	-.162*	-.042	1			
COD (mg/L)	-.169*	.078	.095	.451**	-.159*	.561**	-.274**	-.215**	1		
FC (MPN/100 mL)	-.137	-.004	-.107	.087	.466**	.133	.110	.068	.008	1	
BOD (mg/L)	-.308**	-.040	-.042	.344**	-.056	.610**	-.133	-.092	.743**	.017	1

Note: * Correlation is significant at the 0.01 level (2-tailed)
** Correlation is significant at the 0.05 level (2-tailed)

Table 3.4. Correlation between key water quality parameters in the main tributaries of the Mekong River, as monitored by the WQMN, 2023

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	1										
TSS (mg/L)	.076	1									
EC (mS/m)	-.014	-.114*	1								
NO_{3-2} (mg/L)	-.337**	-.009	.384**	1							
NH_4N (mg/L)	.104*	.216**	-.049	.070	1						
TOTN (mg/L)	-.301**	-.009	.408**	.857**	.227**	1					
TOTP (mg/L)	.140**	.395**	-.078	.163**	.657**	.199**	1				
DO (mg/L)	.188**	-.025	-.499**	-.345**	.064	-.369**	.054	1			
COD (mg/L)	-.291**	.040	.247**	.396**	-.152**	.436**	-.120*	-.510**	1		
FC (MPN/100 mL)	.171**	.027	-.063	-.033	.408**	-.008	.660**	.051	.101	1	
BOD (mg/L)	-.235**	-.087	.223**	.363**	.006	.415**	.144*	-.252**	.295**	.071	1

Note: * 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 differed from indicator to indicator with statistically significant variations detected by ANOVA for pH, EC, $NO_{3\text{-}2}$, NH_4N, TOTN, TOTP, COD, DO and BOD, at P-values of less than 0.01. In 2023, TSS was the only key water quality indicator (excluding the major cations and anions due to the different sampling frequencies in each MCs) with no statistically significant variation (ANOVA P-value of 0.925) on a spatial scale.

Moreover, pH showed a downward trend from upstream to the Delta (Figures 3.1a). Specifically, pH was slightly higher upstream, at 7.45 on average in three stations (LHK, TCS, LLP) and lower in three stations (VTC, VMH and VMT) in the Delta, for an average of 6.89.

DO showed a wide variation along the mainstream. The DO is higher in the upstream stations (LHK and TCS), slightly reduced at the stations of main cities such as Luang Prabang and Vientiane, and less varied in the remaining part of the mainstream. A clear seasonal trend in which the average DO in the wet season is lower than that in the dry season was observed in most of the mainstream stations, except for LVT and LSV.

NO3-2, TOTN, COD and BOD showed a similar spatial trend: their values in upstream were higher in the middle stream in Cambodia and were the highest in the downstream in the delta (Figure 3.2). This trend explains the positive correlation of NO3-2 with TOTN, COD and BOD; it can also explain that the occurrence of NO3-2 TOTN, COD, and BOD was from the same source such as anthropogenic activities (Wang et al., 2007; Xiaolong et al., 2010; Chu et al., 2021).

An increase trend of NH4-N was observed from upstream to downstream. In particular, the average NH4-N concentration in the wet season was higher than that in the dry season at all stations of the mainstream. A similar observation was recorded for TOTP concentrations. However, it should be noted that the TOTP concentrations in the wet season of 2023 at the stations in Cambodia were exceptionally higher than that at other stations (Figure 3.2d).

In comparison to the EC in 2022, the average EC in downstream in the Delta was not the highest among the stations, although the highest EC was observed at VTM with a value of 78.3 mS/m (station in the delta). The station with the highest average EC was at LHK, the most upstream station, at 33.15. The spatial trend of average EC was highest in the upstream, decreased in the middle stream, and increased in the downstream in the Delta (Figure 3.1c).

FC levels also varied at monitored stations (Figure 3.3d). The average FC was below the threshold values of the WQGH (1,000 MPN/100 ml) at all stations in Lao PDR, and two stations in Viet Nam (VMH and VTC). All the stations that monitored FC in Thailand and Cambodia and one station in Viet Nam (VMT) recorded average FC values exceeding the target values of WQGH (1,000 MPN/100 ml). The FC also showed a seasonal trend, i.e. with a higher concentration in the wet season, and a lower concentration in the dry season. Given that most FC concentrations that exceeded the WQGH target value (1,000 MPN/100 ml) were recorded during the wet season months, instream FC levels may have been influenced by run-off water discharged into urbanizing areas of MCs. Therefore, the elevated FC levels should be considered when utilizing the Mekong River and its tributaries as drinking water, and the World Health Organization (WHO) *Guidelines for Drinking-Water Quality* must be strictly observed (WHO, 2011).

Although there was no statistically significant spatial variation in TSS, there was a difference between the wet and the dry seasons, i.e. the average TSS in the wet season was four times higher than that in the dry season (Table 3.1). The high TSS in the wet season can be explained by the increase in flow rate, sediment discharge, and the disturbance of the riverbed due to the fast water flow in the wet season.

In summary, except for TSS, all parameters showed significant spatial variations along the mainstream of the Mekong River. The seasonal trend mostly showed an increase in the wet season and a decrease in the dry season.

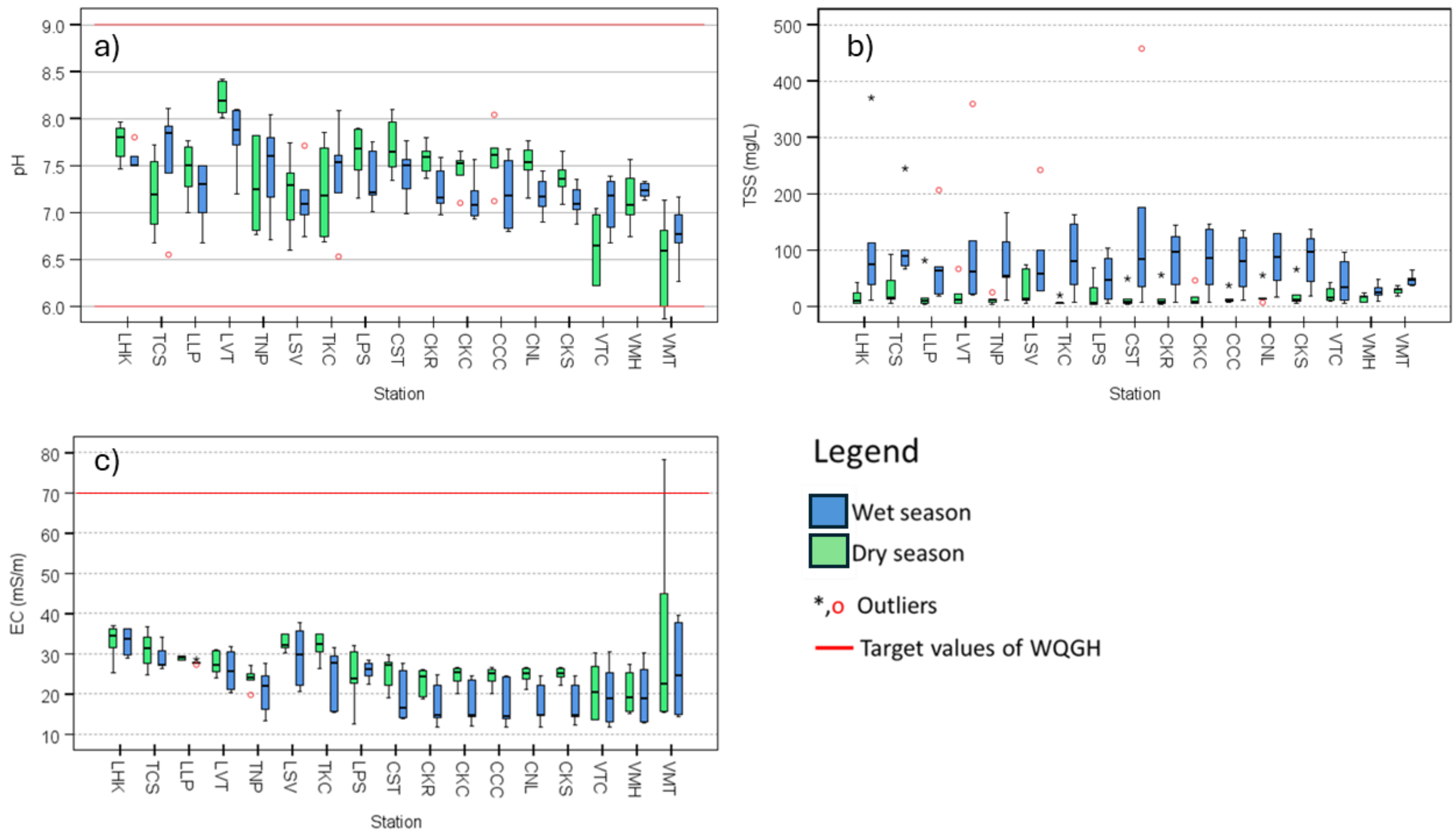

Figure 3.1. Seasonal spatial distribution of (a) pH, (b) EC and (c) TSS levels along the Mekong River, from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)

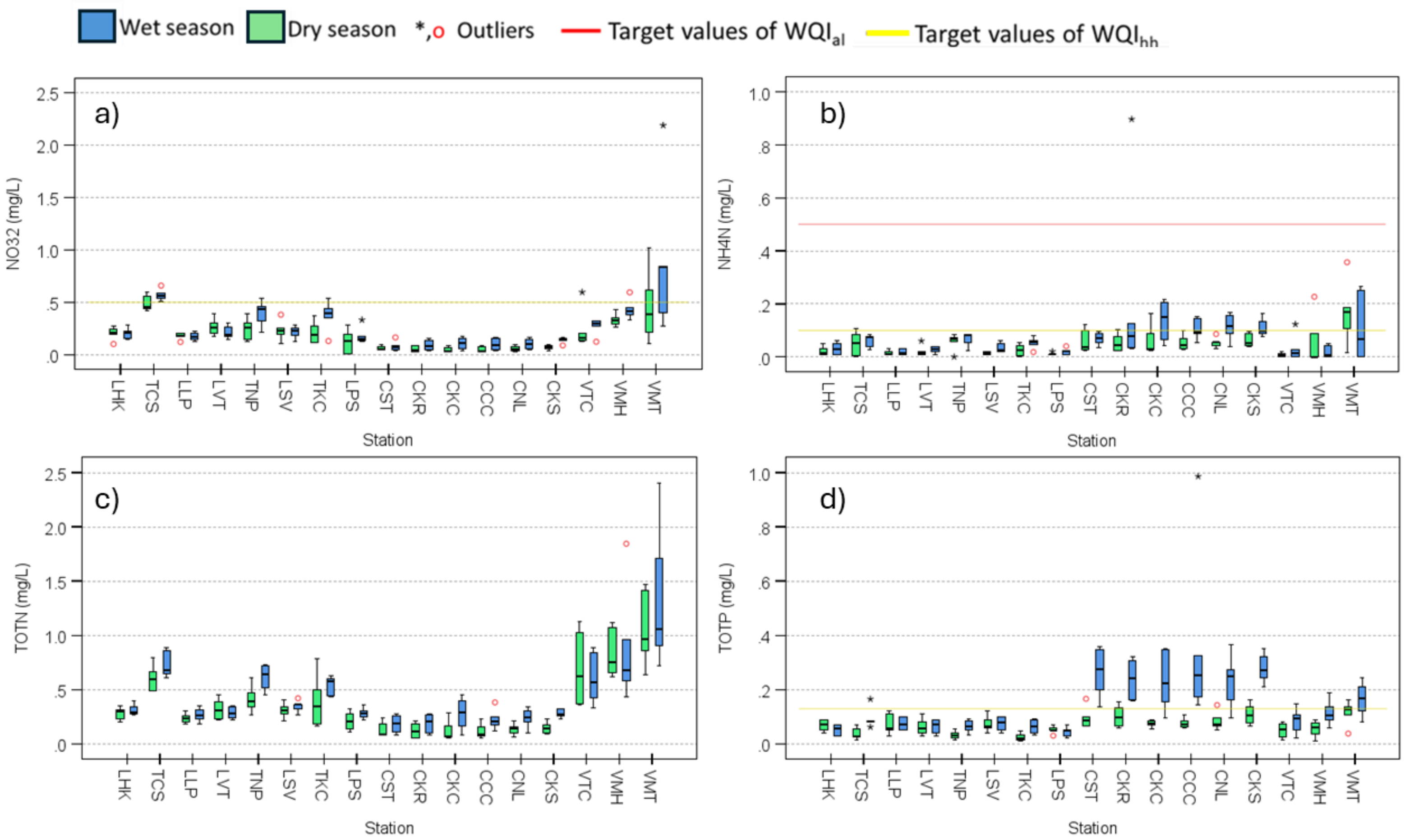

Figure 3.2. Seasonal spatial distribution of (a) $NO_{3\text{-}2}$, (b) NH_4N, (c) TOTN and (d) TOTP levels along the Mekong River, from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)

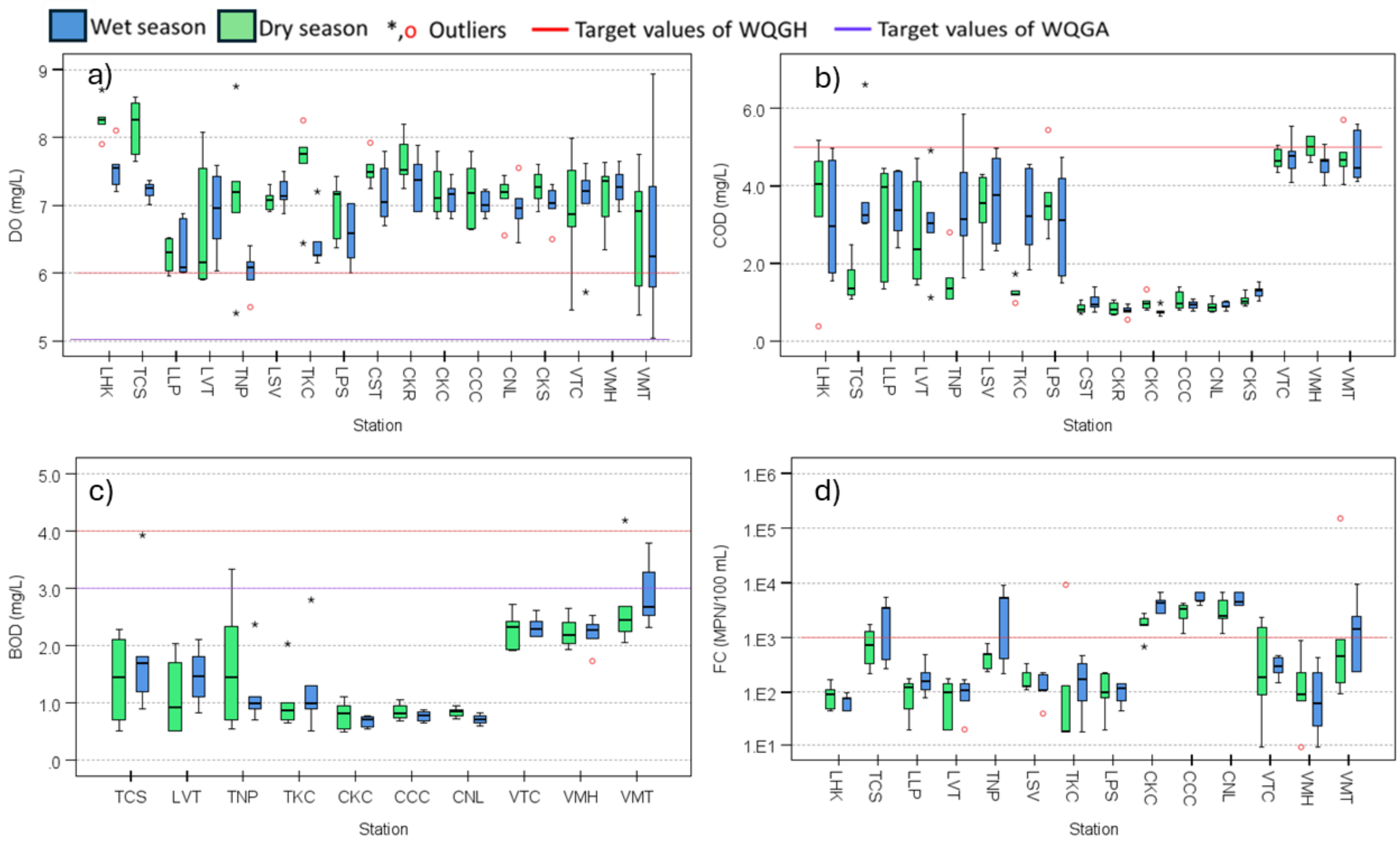

Figure 3.3. Seasonal spatial distribution of (a) DO, (b) COD, (c) BOD and (d) FC levels along the Mekong River, from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)

Note: 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 Figures 3.4, 3.5 and 3.6. In these figures and for the purposes of spatial assessment and comparison, the tributary stations have been classified into the following six groups based on their geographical and sub-basin locations (Table 2.2):

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

The water quality indicators examined in this report showed a significant spatial variation among tributaries. pH was within the WQGH and WQGA in all stations of six tributaries; the average pH was higher in Lao PDR (7.22), Thailand's tributaries (7.17) and the 3S River System (7.16), and lower in the Bassac River System (7.11) and Viet Nam's Delta (6.80) (Figure 3.4). The highest average pH value was observed in Tonle Sap River System at 7.32. In each tributary, the pH value showed a statistically significant spatial variation in 3S, Bassac River System and Viet Nam's Delta, and no spatial variation was observed in the other tributaries.

At all tributaries, the EC values were below the target range of WQGH (70–150 mS/m), except for LHM station. As mentioned in section 3.1.2, EC values at this station were occasionally within the WQGH in the dry season. The highest average EC in LHM (81.6 mS/m, on average) suggests that agriculture, urbanization and population growth affected the water quality (Tromboni et al., 2021). These impacts on water quality were also indicated by the higher concentrations of nitrogen parameters (NO_{3-2}, NH_4H, TOTN), TOTP and COD, which are associated with lower DO values at LHM than the other stations in Lao PDR tributaries (Figures 3.5 and 3.6). Similar to LHM, the nitrogen parameters (NO_{3-2}, NH_4H, TOTN) were higher at the stations of Viet Nam in 3S, Tonle Sap River Systems and Viet Nam's Delta (Figure 3.5). The causes for the higher nitrogen contamination may be related to the intensive agriculture expansion in the Highland areas of Central Viet Nam (Muller and Zeller, 2002; Tram et al., 2022) and the growth of industrial activity in Viet Nam Mekong Delta (Wehrheim et al., 2023), which increased the nitrogen inputs into the rivers. NO3-2 and TOTN showed significant spatial variation in most tributaries excepting in Tonle Sap River System. There was no significant spatial variation of NH4-N in Thailand's tributaries, 3S, Tonle Sap River Systems and Viet Nam's Delta. For TOTP, only 3S River System showed no significant spatial variation. Although nutrients are essential for aquatic plants and animals, their high concentrations are potential causes for water quality issues such as accelerating algae blooms and reduced DO levels for aquatic fauna (USEPA, 2012c). The effects of nutrients on decreasing DO were evidenced by their significant negative correlation of DO with NO3-2 and TOTN (Table 3.4). Therefore, it is recommended to continue monitoring and conduct further analyses on the sources of increasing nutrients instream in order to identify risks of water quality issues and develop proactive action plans.

For COD, the significant spatial variation was observed in 3S, Bassac and Tonle Sap River System, which showed a downward trend from upstream to downstream (Figure 3.6b). The highest COD was continuously recorded at TCR station of Thailand's tributaries, at 9.49 mg/L in July 2023 (see section 3.1.2). The highest average COD was recorded in Viet Nam's Delta, at 5.11 mg/L.

DO showed significant spatial variation in Lao PDR's tributaries, Bassac River System and Viet Nam's Delta. The less spatial variation of DO with higher DO values indicated that the water quality in tributaries also improved compared to that in 2022.

TSS was spatially varied among tributaries. Similar to 2022, the highest TSS was recorded in Tonle Sap River System with a value of 1,051 mg/L in April 2023 at CPK, indicating that the periodical influence of instream and/or bank activities, including inland water navigations and fishery activities, remained in 2023 (Ang & Oeurng, 2018; Ratha, Grenouillet & Lek, 2016). However, the water quality in terms of TSS improved downstream of Tonle Sap River System (Figure 3.4). In each tributary, significant variations of TSS were recorded in Thailand's tributary and Tonle Sap River System.

A significant spatial variation of FC was only observed in Lao PDR's tributaries. The highest FC was 32,000 MPN/100 ml at CTK, in the Bassac River System, which is about seven times lower that the highest FC observed at VCD (210,000 MPN/100 ml) in 2022. Among the tributaries, the FC occasionally exceeded the WQGH (1,000 MPN/100 ml) in Lao PDR, Thailand's tributaries, the 3S River System, and more frequently in Tonle Sap, the Bassac River System and Viet Nam's Delta (see section 3.1.2).

The spatial variations BOD was found in Lao PDR's tributaries and Bassac River System. BOD values exceeding the WQGA (3 mg/L) were recorded in Lao PDR (at LHM), Thailand's tributaries (at TBC) and Bassac River System (at CTK, CKT and VCD).

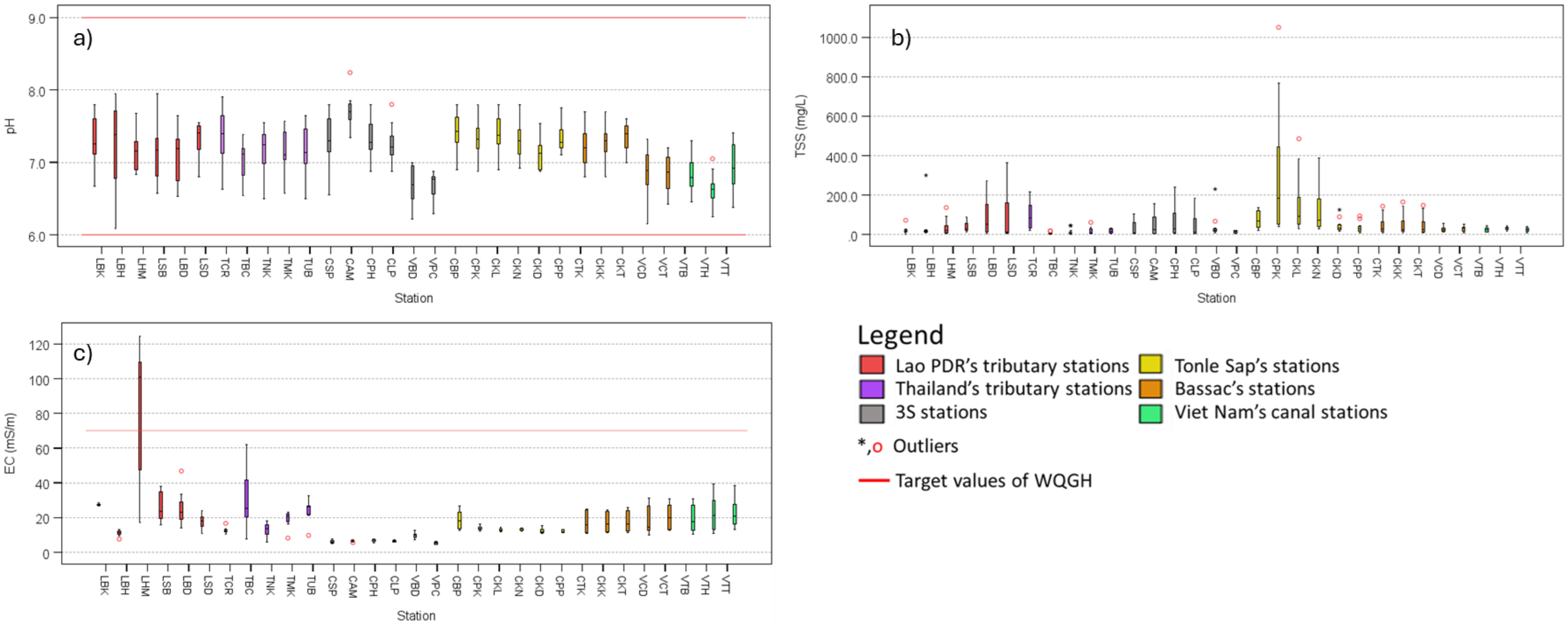

Figure 3.4. Spatial distribution of (a) pH, (b) EC and (c) TSS levels at key tributaries of the Mekong River, 2023

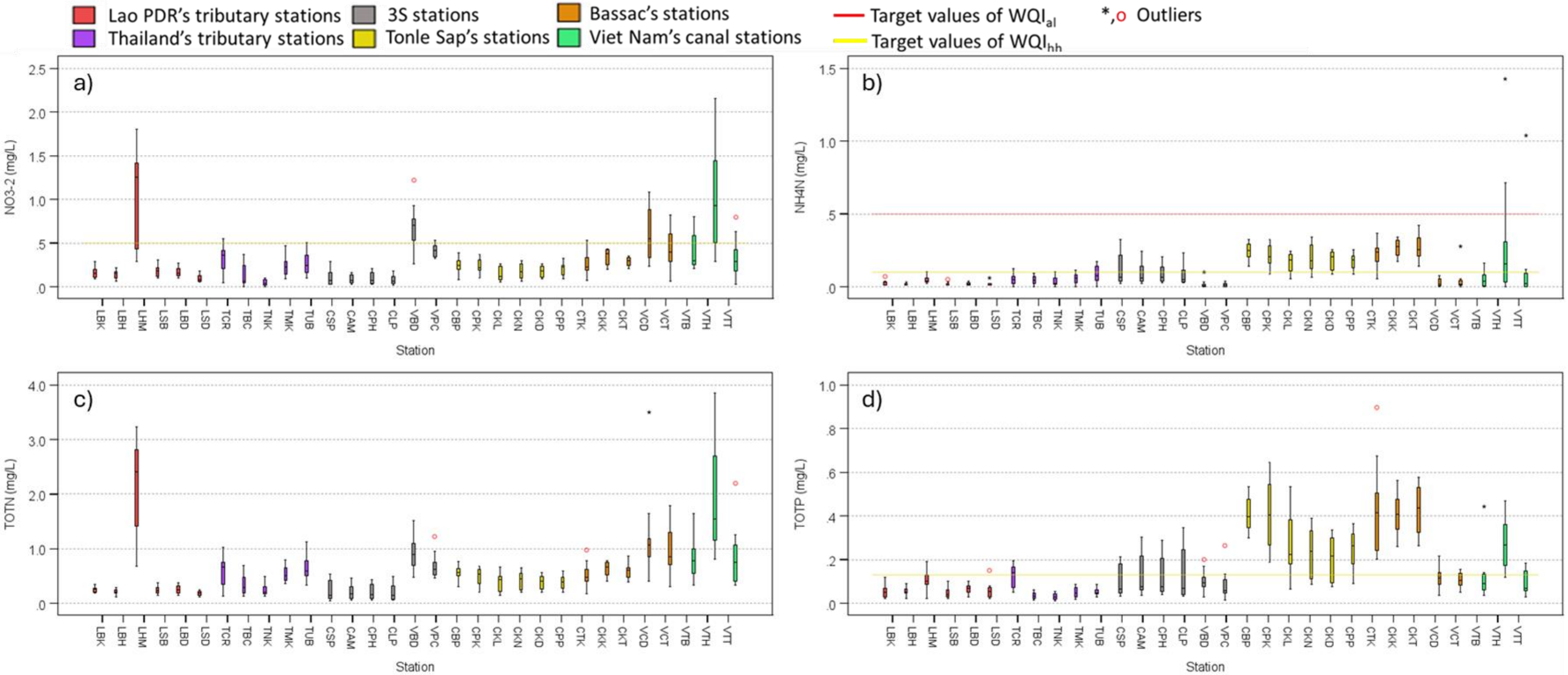

Figure 3.5. Spatial distribution of (a) $NO_{3\text{-}2}$, (b) NH_4N, (c) TOTN and (d) TOTP levels at key tributaries of the Mekong River, 2023

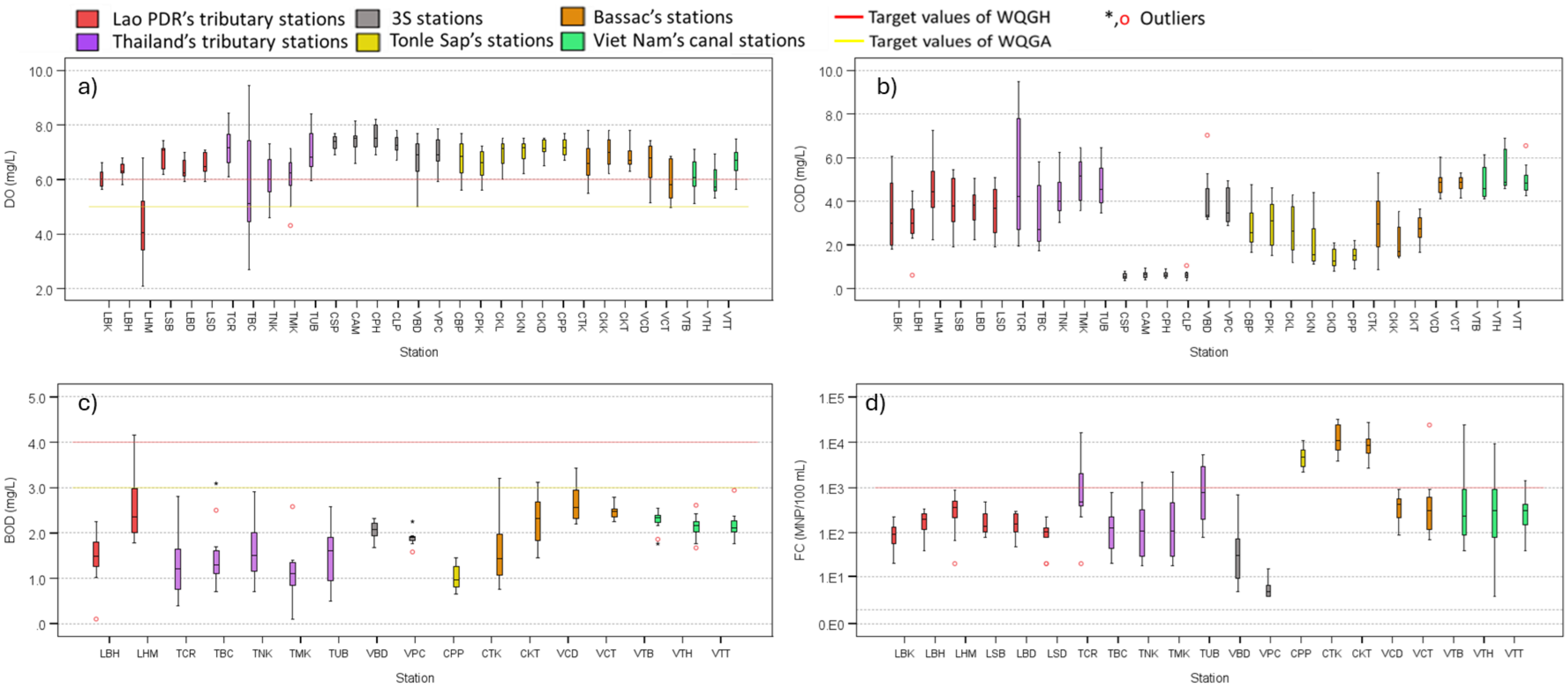

Figure 3.6. Spatial distribution of (a) DO, (b) COD, (c) BOD and (d) FC levels at key tributaries of the Mekong River, 2023

3.3.2 Temporal variations of water quality

Given that the key monitoring objective of routine WQMN in 2023 was 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 that exceeded and were in noncompliance with the target values of WQGH (Chapter 1) and WQGA (Chapter 2). These parameters were identified and discussed in Section 3.1 and Tables 3.1 and 3.2, and include EC, DO and COD. Their temporal variations are discussed in detail below.

3.3.2.1 Electrical Conductivity

EC is one of the useful water quality indicators monitored by the MRC WQMN. It provides a valuable baseline that has been used to identify any emerging effects of development on water quality in the Mekong River. It is also the most important parameter in determining 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 and paddy rice irrigation are listed in Tables 1.3, 1.4 and 2.8.

Under normal circumstance and in areas that are not affected by salinity intrusion, the Mekong and Bassac Rivers, similar to other water bodies, have constant ranges of EC, and therefore, any sudden and significant change in EC 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 conditions, EC is influenced by the amount of dissolved inorganic solids from surrounding soils and geology (Ohtani, 2013). Therefore, significant changes in EC levels in the river could indicate increased pollution levels from different sources, even if its physical characteristics (i.e. colour, smell, clarity, etc.) remain the same. Wetzel (2001) states that pollution from agricultural runoff or sewage leaks can increase the EC level, while a spill of organic compound such as oil can reduce it.

Figure 3.7 illustrates the temporal mean annual EC at the mainstream and tributary stations. The Mekong River and its tributaries are naturally low-salinity rivers with EC values rarely exceeding 50 mS/m when monitored during low tide. The temporal data from 1985 to 2023 show that the EC had exceeded the upper limit value of WQGH (150 mS/m) 26 times at My Tho station (VMT) in the Delta. These values were recorded during the dry season and mostly occurred in April (12 out of 26 times, or 46.2%). The highest EC value was 841.0 mS/m in April 1998, and the highest annual average EC was recorded in 2020, at 206.6 mS/m. Among the tributaries, the annual average EC values that were higher than the lower limit of WQGH (70 mS/m) were recorded at the LHM of Lao PDR's tributaries. At LHM, the water quality has been monitored since 2004, and EC above 70 mS/m has been recorded since 2012. Most of these values were in the dry season, but the highest EC in LHM was in the wet season (July 2017). Based on the Seasonal Mann-Kendall Test results, 64.7% and 83.8% of the stations in mainstream and tributaries, respectively, indicate a significant increasing trend of EC (Annex E). The increase in EC is mainly related to anthropogenic activities, as mentioned above (Okamoto et al., 2014; Ly & Metternicht, 2020). It should be noted that the groundwater discharge to the river can also be a factor in increasing the EC of water in mainstream and tributaries, since the EC of groundwater typically has higher EC values (Schmidt et al., 2012). In addition, the air temperature considered a proxy of climate change should be studied for the effect on the increase of EC since climate change has shown significant impacts on the water bodies, which were observed in the Adige and Ebro River Basins in Europe (Diamantini et al., 2018).

No trend of EC was recorded at LVT, TNP, LSV, TKC, LPS (the mainstream), at LBK (Lao PDR's tributaries), or at TBC, TMK or TUB (Thailand's tributaries). The significant decreasing trend of EC was observed at LSB (Lao PDR's tributaries) and TNK (Thailand's tributaries). A significant decreasing trend of EC at these stations may locally reflect the dominant of more dilute natural water sources such as rain water rather than impact high EC water sources such as anthropogenic discharge into the river.

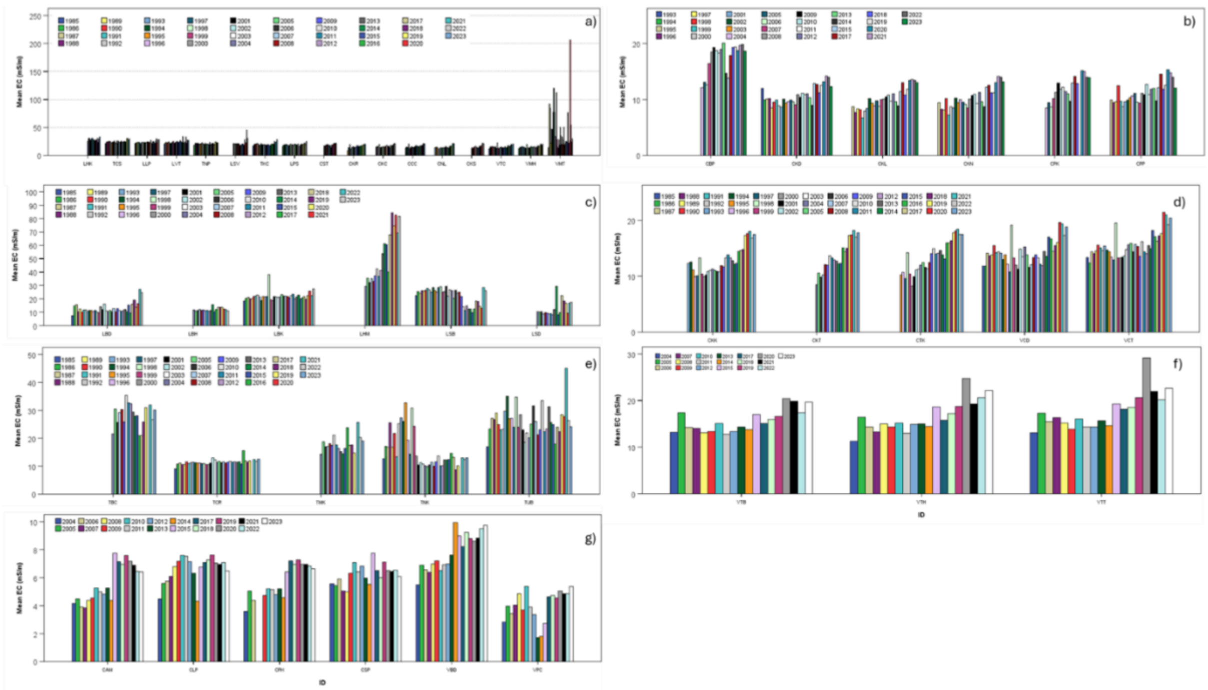

Figure 3.7. Temporal variation of mean annual EC concentrations of 48 water quality monitoring stations along (a) the Mekong River; (b) Tonle Sap's stations; (c) Lao PDR's tributaries stations; (d) Bassac River's stations; (e) Thailand's tributaries stations; (f) Viet Nam's canal stations; and (g) 3S's stations.

3.3.2.2 Dissolved Oxygen

Figure 3.8 shows the temporal trend of DO. The seasonal Mann-Kendall test resulted in a significant decreasing trend of DO in 23 stations in the LMB (Annex E). However, in general, there was no significant increasing or descreasing trend observed at stations in Cambodia, including CST, CKR, CNL (Mainstream), CAM, CLP, CPH, CSP (3S River System), CPK (Tonle Sap River System) and CKT (Bassac River System). The other stations with no DO trend were TCS, LBD, LBH (the mainstream), LSD (Lao PDR's tributaries) and TBC and TCR (Thailand's tributaries). Moreover, 90.9% of stations recorded a significant increasing trend of DO in Cambodia (Annex E), i.e. at CKC, CCC, CNL (the mainstream), CBP, CKD, CKL, CKN, CPP (Tonle Sap River System) and CTK (Bassac River System). The increasing trend of DO was also indicated at LHM, where the lowest mean annual DO was recorded in 2012 (2.89 mg/L). The increase in the temporal trend of DO in LHM suggests that the water quality may have been improved since it was first monitored in 2004. However, in 2004–2022, there was a high proportion of DO concentration that was lower than WQGH (6 mg/L) and WQGA (5 mg/L), at 83.0% and 65.3% of data points, respectively. However, the DO significantly improved in the LMB in 2023, especially in stations in the Mekong Delta.

At TMK (Thailand's tributaries), DO also had annual average values below the WQGH (6 mg/L) for three consecutive years, from 2019 to 2022 (Figure 3.8). But in 2023, the average DO value was above the target value, which is similar to the water quality improvement recorded in Mekong Delta.

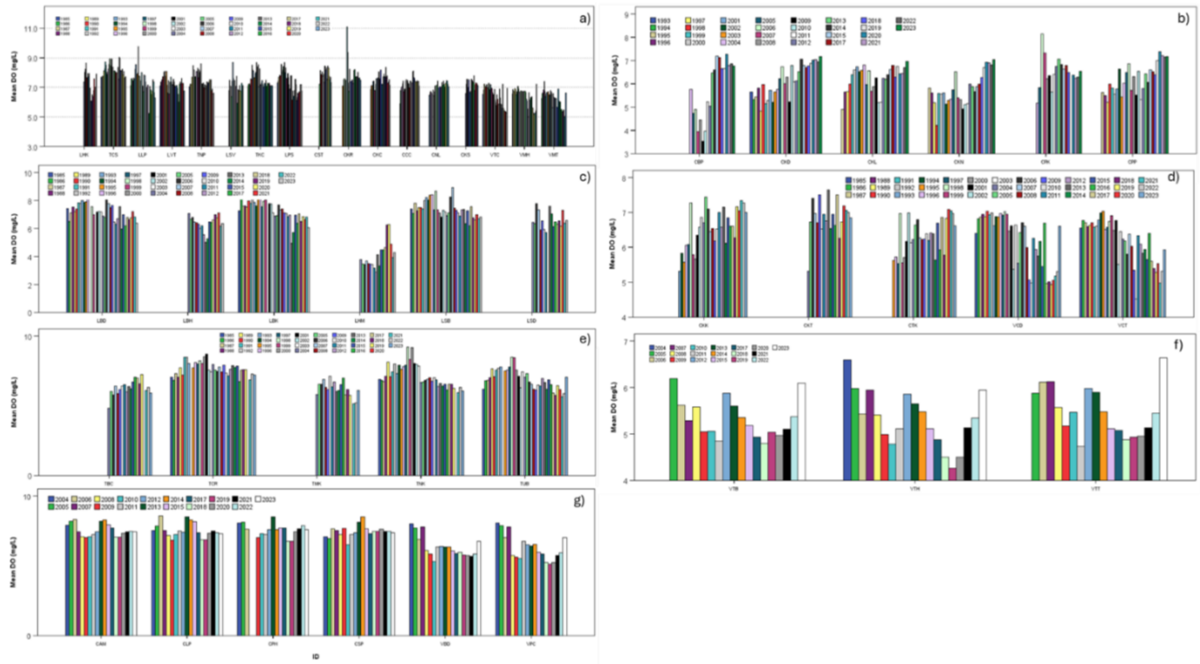

Figure 3.8. Temporal variation of mean annual DO levels of 48 water quality monitoring stations along (a) the Mekong River; (b) Tonle Sap's stations; (c) Lao PDR's tributaries stations; (d) Bassac River's stations; (e) Thailand's tributaries stations; (f) Viet Nam's canal stations; and (g) 3S's stations.

3.3.2.3 Chemical Oxygen Demands

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

Annex E shows the temporal trend of COD in 48 stations based on the Seasonal Mann-Kendall analysis. The COD mainly indicates an increasing trend, at 52.1% of monitoring stations; 27.1% of monitoring stations showed a decreasing trend; and 20.8% of monitoring stations showed no trend. In the mainstream, an increasing trend was observed at stations in Lao PDR, Thailand and Viet Nam's Delta. The annual average COD was mostly below the target value of the WQGH (5 mg/L) at all mainstream stations and occasionally above the target value at TCS (5,49 mg/L in 2004), TNP (5.30 mg/L and 6.97 mg/L, in 2004 and 2008, respectively), VMT (5.01 and 6.26, in 2007 and 2010, respectively), VMH (6.26 mg/L in 2010) and LHK (7.48 mg/L in 2014).

When observing the stations along the tributaries, an annual average COD exceeding the WQGH (5 mg/L) was most frequently observed at TCR (Thailand's tributaries) for 18 out of 20 years over the 2004–2023 period (Figure 3.9). At TUB station, the COD target value regularly exceeded the WQGH (5 mg/L). The temporal data at Thailand's tributaries stations show that the COD was well below the target value of WQGH (5 mg/L) when first monitored in 1985 at TCR (2.2 mg/L) and TUB (3.43 mg/L); however, it drastically increased from 2004. Given that instream COD is 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 TCR and TUB may be a reflection of increased urbanization and industrialization in the respective sub-basins. The issue may also reveal in TNK, where COD showed an increasing trend in COD, although the annual average COD was mostly below the target value (5 mg/L) of WQGH (Figure 3.9).

Interestingly, most of the stations in the mainstream and tributaries of Cambodia showed a decreasing trend of COD (Figure 3.9). This indicates that the water quality improved in terms of COD along mainstream segments and tributaries in Cambodia. Seven out of 10 stations that indicated no significant trend of COD were also in Cambodia, the others were at LSD (Lao PDR's tributaries), TBC (Thailand's tributaries) and VBD (3S River System). No changes in the trend of COD was observed, which suggests that the water quality was maintained since it started monitoring, which was mostly below the target value (5 mg/L) of WQGH.

LHM was among the stations with a decreasing trend of COD, with an annual mean of COD exceeding the target value of the WQGH (5 mg/L). The COD was the highest in October 2020, at 40.6 mg/L, while the overall trend was a significant decrease according to the Seasonal Mann-Kendall (Annex E). During the first full year of water quality monitoring (monthly) at LHM in 2005, the mean COD was 6.54 mg/L, which decreased to 4.62 mg/L in 2023. The lowest annual mean COD was in 2017, with a concentration of 4.24 mg/L.

Temporal data show that the COD exceeding the target value of the WQGH (5 mg/L) was more frequently recorded in the wet season, specifically, 67.8%, 59.7%, 68.6%, 65% and 51.7% in the mainstream, Lao PDR, Thailand's tributaries, 3S River System, and Viet Nam's Delta canals, respectively. In Bassac and Tonle Sap River Systems, COD concentrations greater than 5 mg/L were more often observed in the dry season, at 63.5% and 70.9%, respectively.

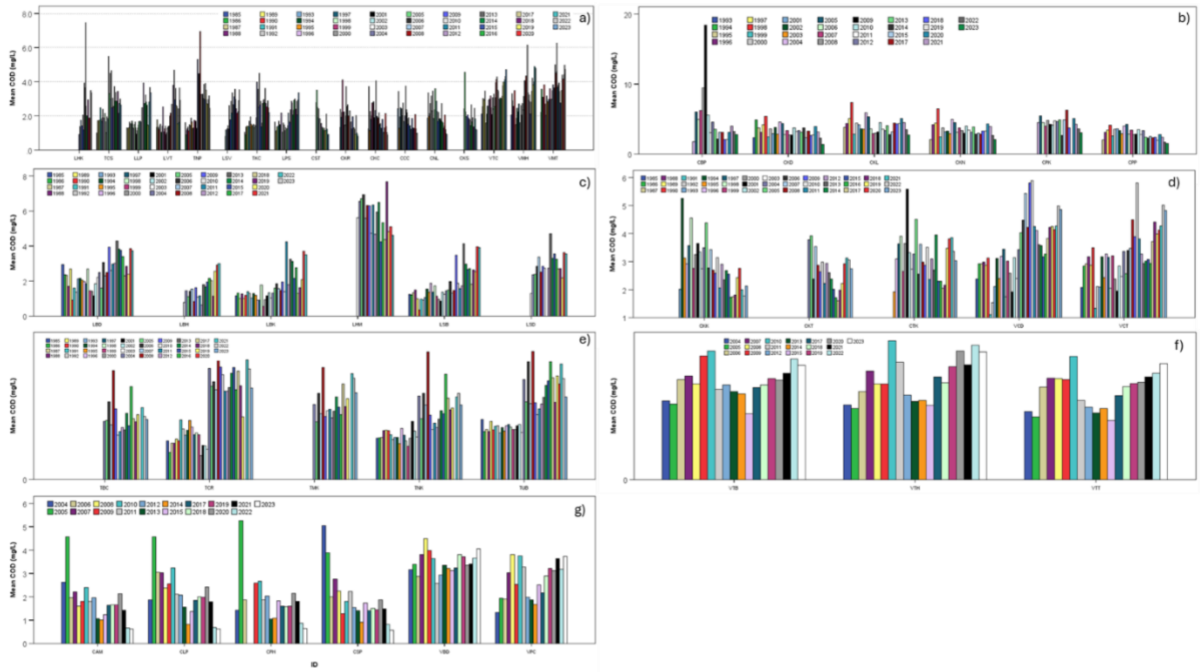

Figure 3.9. Temporal variation of mean annual COD levels of 48 water quality monitoring stations along (a) the Mekong River; (b) Tonle Sap's stations; (c) Lao PDR's tributaries stations; (d) Bassac River's stations (e) Thailand's tributaries stations; (f) Viet Nam's canal stations; and (g) 3S's stations.

3.4 TRANSBOUNDARY WATER QUALITY

In the 2023 Water Quality report, three sets of transboundary water quality monitoring are considered part of this regional report, comprising eight stations, including 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.

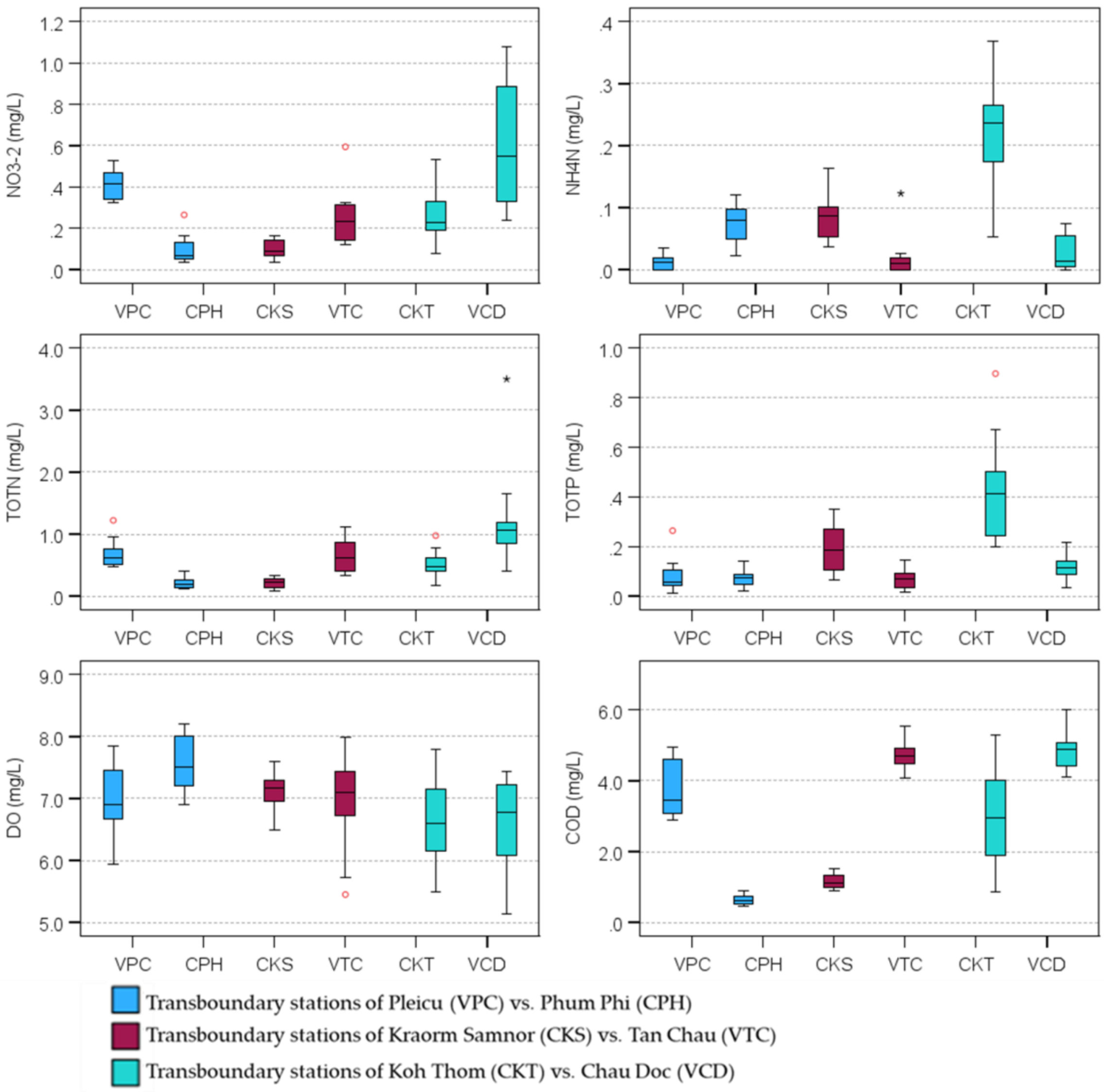

Figure 3.10. Comparisons of 2023 water quality data at the designated transboundary stations of WQMN

3.4.1 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 enters 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 serves as an upstream station of Cambodia's and Viet Nam's national border, whereas CPH is the downstream station located on the Cambodia side of the Se San River.

Table 3.5. Statistical analyses of nutrient parameters monitored at VPC and CPH, 2023

Indicators	Stations	Mean (mg/L)	Std. deviation	P-value
NO3-2	CPH	0.097	0.067	<0.001
	VPC	0.412	0.076	
NH_4N	CPH	0.075	0.034	<0.001
	VPC	0.012	0.013	
TOTN	CPH	0.211	0.082	<0.001
	VPC	0.680	0.221	
TOTP	CPH	0.073	0.034	0.366
	VPC	0.081	0.068	
DO	CPH	7.583	0.434	0.006
	VPC	7.002	0.581	
COD	CPH	0.643	0.148	<0.001
	VPC	3.737	0.779	

In 2023, except for TOTP and DO, statistically significant differences were found for all parameters with P-values less than 0.01. The average values of NO3-2, TOTN, TOTP and COD were higher in the upstream station (VPC) and lower in the downstream station (CPH) (Table 3.5). While DO was lower in VPC and higher in CPH, and slightly increased from upstream to downstream for NH4N. Therefore, the decreased trend observed for the concentrations of NO_{3-2}, TOTN and COD indicates that there was no potential for transboundary water quality.

3.4.2 Kaorm Samnor vs. Tan Chau

Kaorm Samnor (CKS) and Tan Chau (VTC) monitoring stations are located on the Mekong River (CKS on the Cambodian side, and VTC 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 shows the significant differences between CKS and VTC stations in terms of NO3-2, NH4N, TOTN and COD. The data reveal that assessed parameters were degraded at VTC compared to those at CKS, according to the increased concentrations of NO3-2, TOTN and COD from CKS to VTC. Specifically, the mean concentrations of NO3-2, TOTN and COD recorded at VTC were approximately 2, 3 and 4 times higher than those at CKS, respectively. This suggests that there was potential transboundary water quality issues between the two stations.

Although the potential for transboundary water quality was highlighted based on the statistical analysis results, a detailed investigation of impacts of land use on water quality between the two stations is recommended to clarify the potential issue related to transboundary or local land use.

Table 3.6. Statistical analyses of nutrient parameters monitored at CKS and VTC, 2023

Indicators	Stations	Mean (mg/L)	Std. deviation	P-value
NO_{3-2}	CKS	0.103	0.044	<0.001
	VTC	0.251	0.134	
NH_4N	CKS	0.085	0.037	<0.001
	VTC	0.018	0.034	
TOTN	CKS	0.215	0.083	<0.001
	VTC	0.645	0.273	
TOTP	CKS	0.194	0.099	<0.001
	VTC	0.068	0.039	
DO	CKS	7.135	0.289	0.228
	VTC	6.961	0.740	
COD	CKS	1.164	0.194	<0.001
	VTC	4.720	0.044	

3.4.3 Koh Thom vs. Chau Doc

A similar analysis was carried out to explore potential transboundary water quality issues at Koh Thom (CKT) water quality monitoring station (on the Cambodian side of the river) and Chau Doc (VCD) water quality monitoring station (on the Vietnamese side of the river) on the Bassac River. 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 2023.

Table 3.7 shows the statistically significant differences in all evaluated parameters except for DO. With the exception of DO, NH4N and TOTP, the mean values of NO_{3-2}, NH4N, TOTN, and COD recorded in VCD were higher than those at CKT. Specifically, the annual mean value of NO_{3-2} was 0.59 mg/L in VCD while in CKT, it was 0.27 mg/L; mean TOTN was 0.53 mg/L and approximately two times higher; mean TOTN was 1.12 mg/L and three times higher; and mean COD was 4.98 and 1.6 times higher (Table 3.7). As recommended for CKS's and VTC's potential transboundary water quality issues, a detailed analysis of current environmental conditions should be carried out to determine the sources and causes of degradation of water quality downstream.

Table 3.7. Statistical analyses of nutrient parameters monitored at CKT and VCD, 2023

Indicators	Stations	Mean (mg/L)	Std. deviation	P-value
NO_{3-2}	CKT	0.266	0.126	<0.001
	VCD	0.591	0.293	
NH_4N	CKT	0.226	0.082	<0.001
	VCD	0.028	0.029	
TOTN	CKT	0.530	0.207	0.005
	VCD	1.199	0.796	
TOTP	CKT	0.430	0.205	<0.001
	VCD	0.119	0.049	
DO	CKT	6.617	0.698	0.488
	VCD	6.607	0.719	
COD	CKT	3.032	1.374	<0.001
	VCD	4.862	0.550	

3.5 WATER QUALITY INDICES

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

Table 3.8. Water quality status of the Mekong River and its tributaries for the protection of human health, aquatic life, and agricultural use, 2023

Station Abbr.	Station Names	River Names	WQI_{hh}	WQI_{al}	WQI_{ag} (general irrigation)	WQI_{ag} (paddy irrigation)
LHK	Houa Khong	Mekong	B	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
TKC	Khong Chaim	Mekong	A	A	A	A
LPS	Pakse	Mekong	B	A	A	A
CST	Stung Treng	Mekong	A	B	A	A
CKR	Kratie	Mekong	A	B	A	A
CKC	Kampong Cham	Mekong	A	B	A	A
CCC	Chrouy Changvar	Mekong	A	B	A	A
CNL	Neak Loung	Mekong	A	B	A	A

Station Abbr.	Station Names	River Names	WQI_{hh}	WQI_{al}	WQI_{ag} (general irrigation)	WQI_{ag} (paddy irrigation)
CKS	Kaorm Samnor	Mekong	A	B	A	A
VTC	Tan Chau	Mekong	B	A	A	A
VMH	My Thuan	Mekong	B	A	A	A
VMT	My Tho	Mekong	B	B	A	A
Lao PDR's Tributaries						
LBK	Ban Hatkham	Nam Ou	B	A	A	A
LBH	Ban Hai	Nam Ngum	A	A	A	A
LSD	Sedone bridge	Sedone	B	A	A	A
LSB	Se Bangfai	Se Bangfai	B	A	A	A
LBD	Ban Kengdone	Se Banghieng	B	A	A	A
LHM	Houay Mak Hiao	Houay Mak Hiao	C	C	A	A
Thailand's Tributaries						
TCR	Chiang Rai	Mae Kok	B	B	A	A
TBC	Ban Chai Buri	Song Khram	B	B	A	A
TNK	Na Kae	Kam	B	A	A	A
TUB	Ubon	Mun	B	A	A	A
TMK	Mun (Kong Chiam)	Mun	B	A	A	A
Tonle Sap River Basin						
CBP	Backprea	Tonle Sap	A	B	A	A
CPK	Phnom Krom	Tonle Sap Lake	A	B	A	A
CKL	Kampong Luong	Tonle Sap Lake	A	B	A	A
CKN	Kampong Chnang	Tonle Sap	A	B	A	A
CKD	Prek Kdam	Tonle Sap River	A	B	A	A
CPP	Phnom Penh Port	Tonle Sap River	A	B	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	B	A	A
CAM	Angdoung Meas	Se San	A	B	A	A
CLP	Lumphat	Sre Pok	A	B	A	A
CSP	Siempang	Se Kong	A	B	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
Bassac River						
CTK	Takhmao	Bassac	B	B	A	A
CKK	Koh Khel	Bassac	A	B	A	A

Station Abbr.	Station Names	River Names	WQI_{hh}	WQI_{al}	WQI_{ag} (general irrigation)	WQI_{ag} (paddy irrigation)
CKT	Koh Thom	Bassac	A	B	A	A
VCD	Chau Doc	Bassac	B	B	A	A
VCT	Can Tho	Bassac	B	B	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 2023, 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, nine stations were rated as "high" quality, and eight stations were "good" quality for the protection of aquatic life. All stations located on the mainstream stretch of the Mekong River between the Lao PDR/China national border and the Cambodia/Viet Nam national border were assessed from "good" to "high" quality for the protection of aquatic life. At "good" water quality stations, NO3-2 and TOTP are the two parameters exceeding the target values.

Along the tributaries of the Mekong River, the water quality at eight stations were rated as "high" for the protection of aquatic life, while 21 stations were rated "good" and two stations were rated as "moderate". The two stations rated as "moderate" were Houay Mak Hiao (LHM) and Thong Binh (VTH); at these two stations, a combined 26.4% of data points (38 out of 144 data points) exceeded the respective WQI_{al} target value for NO3-2 of WQI_{al} (0.5 mg/L) and TOTP (0.13 mg/L).

Overall, 46 stations (of the 48 WQMN stations) were rated as either "good" or "high" for the protection of aquatic life. This indicated the stability of water quality in the LMB, which maintains good/acceptable quality along the Mekong River and its tributaries.

3.5.2 Water Quality Index for the Protection of Human Health

Analysis of the 2023 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" to "excellent" (Table 3.8). Along the mainstream, nine stations were rated as "excellent" and eight stations as good" for the protection of human health (Table 3.8). At the eight "good" stations, COD was the indicators that did not meet the target value of the WQIhh (5 mg/L).

Along the tributaries, LHM (a tributary station of Lao PDR) was the only station rated as "moderate" for the protection of human health. At LHM, 41.7% of COD concentrations exceeded 5 mg/L (the target value of WQGH), while 33.3% of DO concentrations were lower than the target value used for WQI_{hh} calculation (Table 2.6).

Overall, water quality at 47 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 consider FC levels, which were high at many stations, including those located on the mainstream and within Cambodia’s national border (see Sections 3.1.1 and 3.3.1.1 for further discussions on FC). Therefore, water should be directly consumed from the Mekong River with care and in accordance with the World Health Organization’s *Guidelines for Drinking-Water Quality* (WHO, 2011).

3.5.3 Water Quality Index for Agricultural Use

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

In 2023, the EC at My Tho (VMT) continued to be rated as “no restriction”. This indicates that all EC values fell within the values of the guidelines for the Water Quality Index for General Irrigation Use (70 mS/m). The water quality of the Mekong River and its tributaries was rated as “no restriction” for the general irrigation use at 46 stations (Table 3.8).

From 2008 to 2023, water quality of the Mekong River and its tributaries remained suitable for both general and paddy rice irrigation, with annual WQI_{ag} ratings of mostly “no restriction” (**Annex D**), except in 2016, 2020 and 2021 at My Tho (VMT), due to a prolonged seawater intrusion (**Annex D**), which was investigated as part of the regional study on the extent of salinity intrusion.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

This report provides an overall basin-wide assessment of the water quality of the Mekong River and its tributaries in 2023, using key water quality parameters monitored under the MRC WQMN and listed in Chapters 1 and 2 of the TGWQ as proxies for water quality. The analyses of water quality data collected from 48 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 the Mekong River, 5 along the Bassac River, and 26 in other key tributaries of the Mekong River.

Based on the assessment results of the 2023 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 2023 varied spatially from "good" to "excellent" for the protection of human health at 47 stations, and one station was rated as "moderate". The "moderate" water quality was located in the tributaries of Lao PDR (LHM station), where instream water quality continued to be periodically affected by elevated EC and COD levels, and reduced DO levels. The LHM station is located downstream of major urban centres, which receives effluents from the Vientiane Municipality.
- With regard to the protection of aquatic life, the water quality of the Mekong and its tributaries was rated "good" to "high" at the 46 stations of the WQMN, and three stations were rated "moderate". All 17 stations in the mainstream were aligned with "good" or "high" water quality.
- Elevated FC concentrations continued to be recorded in 2023 at some mainstream and tributary stations, where human activities are intensive. However, the effect was local or not extended to the downstream stations.
- Saltwater intrusion was not observed at VTM, which was rated "no restriction" for both general and paddy irrigation, consecutively for three years, in 2021, 2022 and 2023. However, since water samples were taken monthly, saltwater intrusion may occasionally occur beyond the sampling time. Therefore, the implementation of the automated high frequency water quality telemetry station starting in 2025 will be crucial for identifying the issue downstream of Viet Nam's Delta. At all stations, the 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 areas such as Houay Mak Hiao (LHM) and Thong Binh (VTH), among others. At these stations, DO, COD, BOD, FC and nutrient water quality indicators occasionally exceeded the target values of either WQGH, WQGA, WQI_{hh} and/or WQI_{al}.
- In 2023, the water quality with respect to DO values significantly improved compared with that in 2022. In particular, at the mainstream and tributaries stations in Mekong

Delta, the DO data points with values greater than the target value of the protection of human health (6 mg/L) significantly increased 16.5 times compared with that in 2022, while the DO data points with values greater than target value of the protection of aquatic life (5 mg/L) were 13% more than that in 2022.

- The elevated of nutrients parameter continued indicating the impact on the reduction in DO levels, reflected by their significant negative correlation with DO. Therefore, it is crucial to conduct regional studies to identify sources of nutrients input into the water of the Mekong River and main tributaries, and appropriate remediating solutions.
- In terms of potential transboundary water quality issues in 2023, the analyses of NO_{3-2}, NH_4N, TOTN, TOTP, DO and COD suggest potential transboundary water quality issues between CKT and VCD station, with higher NO_{3-2}, TOTN and COD at VCD than at CKT. Potential transboundary water quality issues were also detected between CKS and VTC stations, with higher NO_{3-2} and TOTN concentrations recorded at VTC than at CKS. The differences in mean concentrations were found to be statistically significant.

4.2 RECOMMENDATIONS

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

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

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

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

existing JEM HYCOS station at Koh Kei, downstream of the Dong Sahong hydropower project in Cambodia.

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

5. REFERENCES

Ai, L., Shi, Z. H., Yin, W., & Huang, X. (2015). Spatial and seasonal patterns in stream water contamination across mountainous watersheds: Linkage with landscape characteristics. *Journal of Hydrology, 523*, 398–408. doi:https://doi.org/10.1016/j.jhydrol.2015.01.082

Al-Mashagbah, A., & Al-Farajat, M. (2013). Assessment of spatial and temporal variability of rainfall data using kriging, Mann Kendall test and the Sen's slope estimates in Jordan from 1980 to 2007. *Research Journal of Environmental and Earth Sciences, 5*(10), 611–618.

Ang, R., & Oeurng, C. (2018). Simulating streamflow in an ungauged catchment of Tonlesap Lake Basin in Cambodia using Soil and Water Assessment Tool (SWAT) model. *Water Science, 32*(1), 89–101. doi:https://doi.org/10.1016/j.wsj.2017.12.002

Azhar, S. C., Aris, A. Z., Yusoff, M. K., Ramli, M. F., & Juahir, H. (2015). Classification of River Water Quality Using Multivariate Analysis. *Procedia Environmental Sciences, 30*, 79–84. doi: https://doi.org/10.1016/j.proenv.2015.10.014

Baird, R. B. (2017). *Standard Methods for the Examination of Water and Wastewater, 23rd*: Water Environment Federation, American Public Health Association, American ….

Benesty, J., Chen, J., Huang, Y., & Cohen, I. (2009). Pearson correlation coefficient. In *Noise reduction in speech processing* (pp. 1-4): Springer.

Boddy, R., & Gordon, S. L. (2009). *Statistical Methods in Practice : for Scientists and Technologists*: John Wiley & Sons.

CCME. (2001). *CCME Water Quality Index 1.0.* Hull.

Chu, X., Wu, D., Wang, H., Zheng, F., Huang, C., & Hu, L. (2021). Spatial Distribution Characteristics and Risk Assessment of Nutrient Elements and Heavy Metals in the Ganjiang River Basin. *Water*, 13(23), 3367.

Connolly, N. M., Pearson, R. G., Loong, D., Maughan, M., & Brodie, J. (2015). Water quality variation along streams with similar agricultural development but contrasting riparian vegetation. *Agriculture, Ecosystems & Environment,* 213, 11–20. https://doi.org/10.1016/j.agee.2015.07.007

Diamantini, E., Lutz, S. R., Mallucci, S., Majone, B., Merz, R., & Bellin, A. (2018). Driver detection of water quality trends in three large European river basins. *Science of the Total Environment*, 612, 49–62.

DuToit, S. H., Steyn, A. G. W., & Stumpf, R. H. (2012). *Graphical exploratory data analysis*. Springer Science & Business Media.

Fisher, M. J., & Marshall, A. P. (2009). Understanding descriptive statistics. *Australian Critical Care, 22*(2), 93-97. https://doi.org/10.1016/j.aucc.2008.11.003

Franzese, M., & Iuliano, A. (2019). Correlation Analysis. In S. Ranganathan, M. Gribskov, K. Nakai, & C. Schönbach (Eds.), *Encyclopedia of Bioinformatics and Computational Biology* (pp. 706–721). Oxford: Academic Press.

Fu, L., & Wang, Y.-G. (2012). Statistical Tools for Analyzing Water Quality Data. *Water Quality Monitoring and Assessment.* https://www.intechopen.com/books/water-quality-monitoring-and-assessment/statistical-tools-for-analyzing-water-quality-data

Gerald, B. (2018). A brief review of independent, dependent and one sample t-test. *International Journal of Applied Mathematics and Theoretical Physics, 4*(2), 50–54.

Gholami, S., & Srikantaswamy, S. (2009). Analysis of agricultural impact on the Cauvery river water around KRS dam. *World Appl Sci J, 6*(8), 1157–1169.

Gu, Q., Hu, H., Ma, L., Sheng, L., Yang, S., Zhang, X., Zhang, M., Zheng, K., & Chen, L. (2019). Characterizing the spatial variations of the relationship between land use and surface water quality using self-organizing map approach. *Ecological Indicators, 102*, 633–643. https://doi.org/10.1016/j.ecolind.2019.03.017

He, D., Lu, Y., Li, Z., & Li, S. (2009). Chapter 14 – Watercourse Environmental Change in Upper Mekong. In I. C. Campbell (Ed.), *The Mekong* (pp. 335–362). San Diego: Academic Press.

Heiberger, R. M., & Neuwirth, E. (2009). One-way ANOVA. In R through Excel (pp. 165–191). Springer.

Hirsch, R. M., Slack, J. R., & Smith, R. A. (1982). Techniques of trend analysis for monthly water quality data. *Water Resources Research, 18*(1), 107–121. doi:10.1029/WR018i001p00107

IBM Corp. (2023). IBM SPSS Statistics for Windows (Version 29.0.2.0). Armonk, NY: IBM Corp.

Johnson, H. O., Gupta, S. C., Vecchia, A. V., & Zvomuya, F. (2009). Assessment of Water Quality Trends in the Minnesota River using Non-Parametric and Parametric Methods. *Journal of Environmental Quality, 38*(3), 1018–1030. https://doi.org/10.2134/jeq2008.0250

Khan, H., Khan, A., & Hall, S. (2005). The Canadian water quality index: a tool for water resources management.

Kim, T. K. (2017). Understanding one-way ANOVA using conceptual figures. *Korean journal of anesthesiology, 70*(1), 22.

Larsen, R. D. (1985). Box-and-whisker plots. *Journal of Chemical Education, 62*(4), 302.

Lee, J., Lee, S., Yu, S., & Rhew, D. (2016). Relationships between water quality parameters in rivers and lakes: BOD5, COD, NBOPs, and TOC. *Environmental Monitoring and Assessment, 188*(4), 252. doi:10.1007/s10661-016-5251-1

Lee, J. H., & Bang, K. W. (2000). Characterization of urban stormwater runoff. *Water Research, 34*(6), 1773-1780. http://dx.doi.org/10.1016/S0043-1354(99)00325-5

Ly, K., Metternicht, G., & Marshall, L. (2020). Linking changes in land cover and land use of the Lower Mekong Basin to instream nitrate and total suspended solids variations. *Sustainability, 12*(7), 2992. https://www.mdpi.com/2071-1050/12/7/2992

MRC. (2018). *2016 Lower Mekong regional water quality monitoring report*. Vientiane, Lao PDR. https://www.mrcmekong.org/assets/Publications/2016-Lower-Mekong-Regional-Water-Quality-Monitoring-Report-14June18-L-Res.pdf

MRC (2019). *State of the Basin Report 2018*. Vientiane, Lao PDR: The Mekong River Commission Secretariat.

Monica, N., & Choi, K. (2016). Temporal and spatial analysis of water quality in Saemangeum watershed using multivariate statistical techniques. *Paddy and Water Environment, 14*(1), 3-17. doi:http://dx.doi.org/10.1007/s10333-014-0475-6

Muller, D., & Zeller, M. (2002). Land use dynamics in the central highlands of Vietnam: a spatial model combining village survey data with satellite imagery interpretation. *Agricultural Economics*, 27(3), 333–354.

Ohtani, E. (2013). Chemical and Physical Properties and Thermal State of the Core. In *Physics and Chemistry of the Deep Earth* (pp. 244–270).

Pal, M., Samal, N., Roy, P., & Biswas Roy, M. (2015). Electrical Conductivity of Lake Water as Environmental Monitoring – A Case Study of Rudra Sagar Lake. *Journal of Environmental Science,Toxicology and Food Technology*.

Ratha, C., Grenouillet, G., & Lek, S. (2016). Evidence of Water Quality Degradation in Lower Mekong Basin Revealed by Self-Organizing Map. *PLoS One, 11*(1). doi:http://dx.doi.org/10.1371/journal.pone.0145527

Ross, A., & Willson, V. L. (2017). One-way ANOVA. In *Basic and advanced statistical tests* (pp. 21–24). Brill Sense.

Schmidt, C., Musolff, A., Trauth, N., Vieweg, M., & Fleckenstein, J. H. (2012). Transient analysis of fluctuations of electrical conductivity as tracer in the stream bed. *Hydrology and Earth System Sciences*, 16(10), 3689–3697.

Statistic Canada. (2021). *Statistics: Power from Data!* Ottawa. https://www150.statcan.gc.ca/n1/edu/power-pouvoir/toc-tdm/5214718-eng.htm

Thirumalai, C., Vignesh, M., & Balaji, R. (2017). *Data analysis using Box and Whisker plot for Lung Cancer.* Paper presented at the 2017 Innovations in Power and Advanced Computing Technologies (i-PACT).

Thompson, J. M. (1992). Visual representation of data including graphical exploratory data analysis. In *Methods of Environmental Data Analysis* (pp. 213–258). Springer.

Tram, V. N. Q., Somura, H., Moroizumi, T., & Maeda, M. (2022). Effects of local land-use policies and anthropogenic activities on water quality in the upstream Sesan River Basin, Vietnam. *Journal of Hydrology: Regional Studie*s, 44, 101225.

Tromboni, F., Dilts, T.E., Null, S.E., Lohani, S., Ngor, P.B., Soum, S., Hogan, Z. and Chandra, S. (2021). Changing land use and population density are degrading water quality in the Lower Mekong Basin. *Water*, 13(14), 1948.

Trung, L. D., Duc, N. A., Nguyen, L. T., Thai, T. H., Khan, A., Rautenstrauch, K., & Schmidt, C. (2018). Assessing cumulative impacts of the proposed Lower Mekong Basin hydropower cascade on the Mekong River floodplains and Delta – Overview of integrated modeling methods and results. *Journal of Hydrology*. https://doi.org/10.1016/j.jhydrol.2018.01.029

UNICEF Cambodia. (2019). Water, Sanitation and Hygiene. *UNICEF Country Programme 2019-2023*. https://www.unicef.org/cambodia/media/2431/file/CountryProgramme_Water,%20Sanitation%20&%20Hygiene.pdf%20.pdf

UNICEF Lao PDR. (2019). Water, Sanitation & Hygiene and Climate Change Resilience. *Safe water, sanitation and good hygiene practices*. https://www.unicef.org/laos/water-sanitation-hygiene-and-climate-change-resilience

von Sperling, M., Verbyla, M. E., & Oliveira, S. M. A. C. (2020). Descriptive statistics: numerical methods for describing monitoring data. In *Assessment of Treatment Plant Performance and Water Quality Data: A Guide for Students, Researchers and Practitioners* (pp. 0): IWA Publishing.

Wang, X. L., Lu, Y. L., Han, J. Y., He, G. Z., & Wang, T. Y. (2007). Identification of anthropogenic influences on water quality of rivers in Taihu watershed. *Journal of Environmental Sciences*, 19(4), 475–481.

Wehrheim, C., Lübken, M., Stolpe, H., & Wichern, M. (2023). Identifying Key Influences on Surface Water Quality in Freshwater Areas of the Vietnamese Mekong Delta from 2018 to 2020. *Water*, 15(7), 1295.

Wetzel, R. G. (2001). 10 - SALINITY OF INLAND WATERS. In R. G. Wetzel (Ed.), *Limnology (Third Edition)* (pp. 169–186). San Diego: Academic Press.

WHO. (2011). *Guidelines for Drinking-Water Quality* (4th edition). Geneva.

Wilcox, R. R. (1990). Comparing the means of two independent groups. *Biometrical Journal, 32*(7), 771–780.

ANNEX A – 2023 WATER QUALITY STATUS OF THE MEKONG RIVER AS MONITORED AT 17 MAINSTREAM STATIONS

Stations[3]	Statistical parameters	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)
	Chapter 1: Guidelines for the Protection of Human Health	6–9	-	70–150	5	-	-	-	≥ 6	5	4
	Chapter 2: Guidelines for the Protection of Aquatic Life	6–9	-	-	5	-	-	-	> 5	-	3
CCC	Maximum	8.04	134.60	26.55	0.17	0.15	0.38	0.99	7.80	1.39	6800
	Mean	7.39	46.16	20.85	0.07	0.08	0.17	0.22	7.09	0.99	4150
	Median	7.51	24.05	23.82	0.06	0.08	0.17	0.13	7.08	0.95	4050
	Minimum	6.80	7.30	11.79	0.02	0.03	0.06	0.06	6.64	0.77	1200
	Std. deviation	0.38	47.08	5.54	0.05	0.04	0.09	0.26	0.35	0.19	1637
CKC	Maximum	7.65	145.90	26.65	0.18	0.22	0.45	0.35	7.80	1.33	6800
	Mean	7.30	49.08	20.94	0.08	0.10	0.20	0.15	7.16	0.88	3040
	Median	7.32	27.20	23.34	0.06	0.08	0.17	0.09	7.13	0.82	2800
	Minimum	6.93	4.50	11.95	0.02	0.02	0.05	0.05	6.80	0.65	680
	Std. deviation	0.26	52.73	5.47	0.05	0.07	0.14	0.11	0.30	0.18	1712
CKR	Maximum	7.80	144.50	26.20	0.15	0.90	0.28	0.32	8.20	1.05	

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

Stations[3]	Statistical parameters	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)
	Chapter 1: Guidelines for the Protection of Human Health	6–9	-	70–150	5	-	-	-	≥ 6	5	4
	Chapter 2: Guidelines for the Protection of Aquatic Life	6–9	-	-	5	-	-	-	> 5	-	3
	Mean	7.41	50.28	20.09	0.07	0.13	0.16	0.17	7.49	0.81	
	Median	7.44	26.15	20.70	0.05	0.05	0.16	0.16	7.48	0.79	
	Minimum	6.98	3.90	11.71	0.03	0.03	0.05	0.06	6.90	0.55	
	Std. deviation	0.26	52.80	5.21	0.04	0.24	0.08	0.09	0.39	0.14	
CKS	Maximum	7.65	135.70	26.55	0.16	0.16	0.33	0.35	7.60	1.53	
	Mean	7.24	52.69	21.09	0.10	0.08	0.21	0.19	7.14	1.16	
	Median	7.26	31.75	23.25	0.09	0.09	0.23	0.19	7.16	1.13	
	Minimum	6.88	5.70	12.32	0.04	0.04	0.09	0.07	6.50	0.90	
	Std. deviation	0.21	48.11	5.34	0.04	0.04	0.08	0.10	0.29	0.19	
CNL	Maximum	7.76	129.10	26.55	0.17	0.17	0.34	0.36	7.55	1.15	6800
	Mean	7.35	50.93	20.94	0.08	0.08	0.19	0.16	7.05	0.90	4183
	Median	7.39	30.45	23.01	0.06	0.07	0.18	0.12	7.10	0.90	4050
	Minimum	6.90	6.80	11.87	0.02	0.03	0.07	0.05	6.45	0.75	1200
	Std. deviation	0.26	46.20	5.40	0.04	0.05	0.09	0.10	0.33	0.12	1905
CST	Maximum	8.10	457.40	29.70	0.16	0.12	0.28	0.36	7.92	1.40	

Stations[3]	Statistical parameters	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)
	Chapter 1: Guidelines for the Protection of Human Health	6–9	-	70–150	5	-	-	-	≥ 6	5	4
	Chapter 2: Guidelines for the Protection of Aquatic Life	6–9	-	-	5	-	-	-	> 5	-	3
	Mean	7.56	77.38	22.36	0.07	0.06	0.16	0.18	7.35	0.92	
	Median	7.53	24.30	24.00	0.06	0.06	0.13	0.15	7.43	0.88	
	Minimum	6.99	2.80	13.76	0.03	0.02	0.08	0.07	6.70	0.69	
	Std. deviation	0.31	130.07	5.96	0.03	0.03	0.08	0.11	0.38	0.20	
LHK	Maximum	7.96	370.00	36.90	0.28	0.06	0.40	0.09	8.70	5.18	170
	Mean	7.66	64.72	33.15	0.20	0.03	0.30	0.06	7.91	3.36	82
	Median	7.60	31.13	34.45	0.21	0.02	0.29	0.06	8.00	3.48	78
	Minimum	7.46	5.33	25.30	0.10	0.01	0.20	0.03	7.20	0.38	45
	Std. deviation	0.18	102.79	3.73	0.05	0.02	0.05	0.02	0.47	1.55	37
LLP	Maximum	7.76	206.30	29.50	0.22	0.03	0.35	0.12	6.87	4.44	490
	Mean	7.34	47.25	28.44	0.17	0.02	0.25	0.07	6.29	3.36	156
	Median	7.40	20.48	28.45	0.18	0.01	0.25	0.07	6.16	3.85	125
	Minimum	6.68	4.00	27.30	0.12	0.01	0.18	0.03	5.96	1.33	20
	Std. deviation	0.31	57.53	0.69	0.03	0.01	0.05	0.03	0.32	1.13	122
LPS	Maximum	7.90	102.40	32.10	0.33	0.04	0.36	0.07	7.42	5.44	230

Stations[3]	Statistical parameters	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)
	Chapter 1: Guidelines for the Protection of Human Health	6–9	-	70–150	5	-	-	-	≥ 6	5	4
	Chapter 2: Guidelines for the Protection of Aquatic Life	6–9	-	-	5	-	-	-	> 5	-	3
	Mean	7.46	34.95	25.18	0.15	0.02	0.25	0.05	6.77	3.36	115
	Median	7.45	19.00	25.80	0.15	0.01	0.27	0.05	6.86	3.38	110
	Minimum	7.01	3.25	12.68	0.01	0.01	0.11	0.02	6.01	1.50	20
	Std. deviation	0.32	36.28	5.15	0.09	0.01	0.08	0.02	0.45	1.14	63
LSV	Maximum	7.74	242.00	37.90	0.38	0.06	0.42	0.12	7.50	4.96	330
	Mean	7.18	57.81	31.01	0.22	0.02	0.33	0.07	7.13	3.55	156
	Median	7.18	38.67	32.10	0.23	0.02	0.33	0.07	7.11	3.56	130
	Minimum	6.60	5.66	20.60	0.10	0.01	0.21	0.04	6.88	1.83	40
	Std. deviation	0.35	65.32	5.42	0.07	0.02	0.06	0.03	0.19	0.99	79
LVT	Maximum	8.42	359.20	31.90	0.39	0.06	0.45	0.11	8.07	4.91	180
	Mean	8.01	63.70	26.77	0.24	0.03	0.30	0.06	6.77	2.90	99
	Median	8.07	21.83	27.20	0.23	0.02	0.29	0.07	6.56	2.94	111
	Minimum	7.20	5.50	20.50	0.14	0.01	0.22	0.03	5.90	1.12	20
	Std. deviation	0.33	99.40	4.14	0.07	0.02	0.07	0.03	0.77	1.25	58
TCS	Maximum	8.11	244.60	36.69	0.66	0.11	0.88	0.17	8.60	6.61	5400

Stations[3]	Statistical parameters	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)
	Chapter 1: Guidelines for the Protection of Human Health	6–9	-	70–150	5	-	-	-	≥ 6	5	4
	Chapter 2: Guidelines for the Protection of Aquatic Life	6–9	-	-	5	-	-	-	> 5	-	3
	Mean	7.37	69.26	30.21	0.52	0.06	0.66	0.06	7.73	2.62	1655
	Median	7.42	66.00	30.61	0.54	0.07	0.64	0.06	7.65	2.49	1100
	Minimum	6.55	5.80	24.85	0.42	0.00	0.49	0.02	7.01	1.08	220
	Std. deviation	0.52	67.84	3.79	0.08	0.03	0.13	0.04	0.58	1.61	1731
TKC	Maximum	8.09	161.60	34.88	0.53	0.08	0.79	0.09	8.25	4.55	9200
	Mean	7.30	43.54	28.30	0.28	0.04	0.46	0.04	7.09	2.19	950
	Median	7.32	7.20	30.44	0.27	0.04	0.45	0.03	7.20	1.73	68
	Minimum	6.53	4.90	15.50	0.11	0.00	0.17	0.01	6.15	0.98	18
	Std. deviation	0.51	58.90	6.81	0.15	0.03	0.19	0.03	0.79	1.32	2740
TNP	Maximum	8.04	166.10	27.72	0.54	0.09	0.73	0.09	8.75	5.86	9200
	Mean	7.36	42.81	22.49	0.31	0.06	0.50	0.05	6.62	2.45	2127
	Median	7.35	12.80	23.84	0.30	0.07	0.47	0.04	6.41	1.63	490
	Minimum	6.71	4.00	13.41	0.12	0.00	0.27	0.02	5.41	1.08	220
	Std. deviation	0.48	52.39	4.41	0.13	0.03	0.16	0.03	0.98	1.53	3080
VMH	Maximum	7.56	48.00	30.20	0.59	0.23	1.84	0.19	7.64	5.29	900

Stations[3]	Statistical parameters	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)
	Chapter 1: Guidelines for the Protection of Human Health	6–9	-	70–150	5	-	-	-	≥ 6	5	4
	Chapter 2: Guidelines for the Protection of Aquatic Life	6–9	-	-	5	-	-	-	> 5	-	3
	Mean	7.19	21.00	20.18	0.38	0.04	0.85	0.08	7.22	4.78	185
	Median	7.19	20.00	19.11	0.36	0.00	0.71	0.08	7.36	4.74	90
	Minimum	6.74	7.00	12.90	0.26	0.00	0.43	0.01	6.35	4.00	9
	Std. deviation	0.21	11.57	6.28	0.09	0.07	0.38	0.05	0.38	0.39	257
VMT	Maximum	7.16	65.00	78.30	2.19	0.36	2.40	0.24	8.94	5.70	150000
	Mean	6.64	37.75	29.63	0.67	0.14	1.18	0.14	6.63	4.73	13979
	Median	6.71	36.50	22.63	0.55	0.13	0.99	0.13	6.63	4.57	930
	Minimum	5.87	19.00	14.50	0.10	0.00	0.64	0.04	5.04	4.04	93
	Std. deviation	0.41	12.68	18.89	0.56	0.11	0.50	0.06	1.10	0.56	42912
VTC	Maximum	7.39	95.00	30.40	0.59	0.12	1.13	0.15	7.98	5.53	2300
	Mean	6.86	32.08	20.30	0.25	0.02	0.64	0.07	6.96	4.72	515
	Median	6.97	21.00	20.62	0.23	0.01	0.62	0.07	7.10	4.70	230
	Minimum	6.22	6.00	11.70	0.12	0.00	0.33	0.02	5.45	4.08	9
	Std. deviation	0.42	28.74	7.07	0.13	0.03	0.27	0.04	0.74	0.38	683
Total	Maximum	8.42	457.40	78.30	2.19	0.90	2.40	0.99	8.94	6.61	150000

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

No.	Station Names	Countries	Class														
			2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
1	Houa Khong	Lao PDR	A	A	A	B	B	B	B	B	B	B	A	A	A	A	A
2	Chiang Sean	Thailand	B	B	A	B	B	A	B	B	B	B	A	B	B	B	B
3	Luang Prabang	Lao PDR	A	B	A	A	B	B	B	A	B	A	A	A	A	A	A
4	Vientiane	Lao PDR	A	A	A	A	B	B	A	A	A	A	A	A	A	A	A
5	Nakhon Phanom	Thailand	A	B	A	B	B	A	A	B	B	B	A	A	A	A	A
6	Savannakhet	Lao PDR	A	A	A	A	B	B	B	A	A	B	A	A	A	A	A
7	Khong Chaim	Thailand	A	A	A	A	B	A	A	A	B	A	A	A	A	A	A
8	Pakse	Lao PDR	A	A	A	A	B	B	B	A	A	B	A	A	A	A	A
9	Stung Treng	Cambodia	B	B	B	B	B	B	B	B	A	A	A	A	A	A	B
10	Kratie	Cambodia	B	B	B	B	B	B	B	A	B	B	B	A	A	A	B
11	Kampong Cham	Cambodia	B	B	B	B	B	A	B	A	A	B	B	A	A	A	B
12	Chrouy Changvar	Cambodia	B	B	B	B	B	B	B	A	A	B	B	A	A	A	B
13	Neak Loung	Cambodia	B	B	B	B	B	B	B	A	A	B	A	A	A	A	B
14	Kaorm Samnor	Cambodia	B	B	B	B	B	B	B	A	A	B	A	A	A	A	B
15	Tan Chau	Viet Nam	B	B	B	B	B	B	B	B	A	B	B	B	B	B	A
16	My Thuan	Viet Nam	B	B	B	B	B	B	B	B	B	B	B	B	B	B	A
17	My Tho	Viet Nam	C	C	C	B	C	C	C	D	C	B	C	C	C	C	B
18	Takhmao	Cambodia	B	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	A	B	B
20	Koh Thom	Cambodia	B	B	B	B	B	A	B	B	B	B	A	B	A	B	B
21	Chau Doc	Viet Nam	B	B	B	B	B	B	B	B	B	C	C	C	B	B	B
22	Can Tho	Viet Nam	C	C	C	C	C	B	B	B	B	B	C	C	C	B	B

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														
			2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
1	Houa Khong	Lao PDR	A	B	A	B	B	C	A	A	A	B	A	A	A	B	B
2	Chiang Sean	Thailand	B	B	A	B	B	B	B	B	B	B	A	A	B	B	B
3	Luang Prabang	Lao PDR	A	B	A	B	A	B	B	B	A	B	A	A	A	A	A
4	Vientiane	Lao PDR	A	B	A	B	B	B	B	B	A	A	A	B	A	B	A
5	Nakhon Phanom	Thailand	B	B	B	B	B	B	B	B	B	B	B	A	B	B	B
6	Savannakhet	Lao PDR	A	A	A	B	B	C	B	B	A	A	A	A	A	B	A
7	Khong Chaim	Thailand	B	B	A	B	B	B	B	B	B	B	A	B	B	A	A
8	Pakse	Lao PDR	A	A	A	A	B	A	B	B	A	A	A	B	A	A	B
9	Stung Treng	Cambodia	A	A	A	A	A	A	A	A	A	A	A	B	A	A	A
10	Kratie	Cambodia	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
11	Kampong Cham	Cambodia	A	A	A	A	A	A	B	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	A
13	Neak Loung	Cambodia	A	A	A	A	A	A	B	A	A	A	A	A	A	A	A
14	Kaorm Samnor	Cambodia	A	A	A	B	A	A	B	A	A	A	A	A	A	A	A
15	Tan Chau	Viet Nam	C	B	B	A	A	A	A	A	A	B	B	A	B	B	B
16	My Thuan	Viet Nam	B	C	A	A	B	A	A	A	B	B	A	B	B	B	B
17	My Tho	Viet Nam	C	C	B	B	B	B	A	B	B	B	A	B	C	B	B
18	Takhmao	Cambodia	A	A	A	A	B	C	A	B	A	B	B	B	B	B	B
19	Koh Khel	Cambodia	A	B	A	B	B	A	B	A	A	A	A	A	A	A	A
20	Koh Thom	Cambodia	A	A	A	B	B	A	A	A	A	A	A	A	A	A	A
21	Chau Doc	Viet Nam	C	C	B	B	A	A	A	A	B	B	B	A	B	B	B
22	Can Tho	Viet Nam	B	C	B	A	A	A	A	A	A	B	A	A	B	B	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														
			2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
1	Houa Khong	Lao PDR	A	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	A
3	Luang Prabang	Lao PDR	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
4	Vientiane	Lao PDR	A	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	A
6	Savannakhet	Lao PDR	A	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	A
8	Pakse	Lao PDR	A	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	A
10	Kratie	Cambodia	A	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	A
12	Chrouy Changvar	Cambodia	A	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	A
14	Kaorm Samnor	Cambodia	A	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	A
16	My Thuan	Viet Nam	A	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	B	A	A	A	C	B	A	A
18	Takhmao	Cambodia	A	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	A
20	Koh Thom	Cambodia	A	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	A
22	Can Tho	Viet Nam	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

A – No Restriction

B – Some Restriction

C – Severe Restriction

APPENDIX E - TEMPORAL TREND OF WATER QUALITY IN THE MEKONG AND TRIBUTARIES BASED ON MONTHLY DATA, 1985–2023

	Stations	EC	P-value	DO	P-value	COD	P-value
Mainstream	LHK	No	0.11	D	0.00	I	0.00
	TCS	I	0.00	No	0.89	I	0.00
	LLP	I	0.00	D	0.00	I	0.00
	LVT	No	0.07	D	0.00	I	0.00
	TNP	No	0.95	D	0.00	I	0.00
	LSV	No	0.18	D	0.02	I	0.00
	TKC	No	0.55	D	0.00	I	0.00
	LPS	No	0.73	D	0.00	I	0.00
	CST	I	0.00	No	0.34	D	0.00
	CKR	I	0.00	No	0.08	D	0.00
	CKC	I	0.00	I	0.00	D	0.00
	CCC	I	0.00	I	0.00	No	0.36
	CNL	I	0.00	I	0.00	D	0.00
	CKS	I	0.00	No	0.12	D	0.00
	VTC	I	0.00	D	0.00	I	0.00
	VMH	I	0.00	D	0.00	I	0.00
	VMT	I	0.00	D	0.00	I	0.00
Lao PDR's tributaries	LBD	I	0.00	D	0.00	I	0.00
	LBH	I	0.00	No	0.89	I	0.00
	LBK	No	0.33	D	0.00	I	0.00

	Stations	EC	P-value	DO	P-value	COD	P-value
	LHM	I	0.00	I	0.00	D	0.00
	LSB	D	0.00	D	0.00	I	0.00
	LSD	I	0.00	No	0.41	No	0.23
Thailand's tributaries	TBC	No	0.89	No	0.17	No	0.75
	TCR	I	0.00	No	0.50	I	0.00
	TMK	No	0.08	D	0.00	I	0.00
	TNK	D	0.00	D	0.00	I	0.00
	TUB	No	0.52	D	0.00	I	0.00
3S River System	CAM	I	0.00	No	0.08	D	0.01
	CLP	I	0.00	No	0.09	D	0.00
	CPH	I	0.00	No	0.52	No	0.08
	CSP	I	0.05	No	0.88	D	0.00
	VBD	I	0.00	D	0.00	No	0.15
	VPC	I	0.00	D	0.00	I	0.00
Tonle Sap River System	CBP	I	0.00	I	0.00	D	0.00
	CKD	I	0.00	I	0.00	D	0.00
	CKL	I	0.00	I	0.03	No	0.12
	CKN	I	0.00	I	0.00	No	0.17
	CPK	I	0.00	No	0.17	No	0.11
	CPP	I	0.00	I	0.00	D	0.00
Bassac River System	CKK	I	0.00	I	0.00	D	0.00
	CKT	I	0.00	No	0.58	No	0.66
	CTK	I	0.00	I	0.00	No	0.42
	VCD	I	0.00	D	0.00	I	0.00

	Stations	EC	P-value	DO	P-value	COD	P-value
	VCT	I	0.00	D	0.00	I	0.00
Viet Nam's Delta Canal	VTB	I	0.00	D	0.00	I	0.02
	VTH	I	0.00	D	0.00	I	0.00
	VTT	I	0.00	D	0.00	I	0.00

Note: I: Increasing trend; D: Decreasing trend; No: No temporal trend.

Mekong River Commission Secretariat

P. O. Box 6101, 184 Fa Ngoum Road, Unit 18 Ban Sithane Neua,
Sikhottabong District, Vientiane 01000, Lao PDR
Tel: +856 21 263 263. Fax: +856 21 263 264
www.mrcmekong.org