Lower Mekong Water Quality Monitoring report 2024







June 2026

2024 LOWER MEKONG WATER QUALITY MONITORING REPORT

June 2026

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
EC	Electrical conductivity
FC	Faecal coliform
HH	Guidelines for the Protection of Human Health
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LMB	Lower Mekong Basin
MC	Member Country
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NH4N	Ammonium
NO_{3-2}	Nitrate-nitrite
PDIES	Procedures for Data and Information Exchange and Sharing
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
3S	Sesan, Sekong and Srepok
TOTN	Total nitrogen
TOTP	Total phosphorus
TSS	Total suspended solids
WQGA MRC	MRC Water Quality Guidelines for the Protection of Aquatic Life
WQGH MRC	MRC Water Quality Guidelines for the Protection of Human Health
WQI	Water Quality Index
WQI_{ag}	Water Quality Index for Agricultural Use
WQI_{al}	Water Quality Index for the Protection of Aquatic Life
WQI_{hh}	Water Quality Index for the Protection of Human Health
WQMN	Water Quality Monitoring Network

EXECUTIVE SUMMARY

The Mekong River Commission's (MRC) Water Quality Monitoring Network (WQMN), which was established in 1985, has provided a continuous time series of water quality data on the Mekong River and its tributaries. The routine water quality monitoring under the WQMN is one of the MRC key environmental monitoring activities and is being carried out to support the implementation of the Procedures of Water Quality (PWQ) and its Technical Guidelines. The actual monitoring of water quality is being implemented by the designated laboratories of the Member Countries (MCs) (Cambodia, Lao PDR, Thailand and Viet Nam) with technical support from the Environmental Management Division of the Mekong River Commission Secretariat (MRCS).

In 2024, routine water quality monitoring of the Mekong River and its tributaries continued to be conducted at 48 stations, of which 17 were located along the Mekong mainstream and 31 in key tributaries of the Mekong River, including five stations along the Bassac River. At each station, 19 water quality parameters were monitored, of which 13 were considered routine and were monitored monthly. The other six parameters (i.e. major anions and cations) were also monitored with different frequencies among the MCs: monthly for Thailand and Cambodia; April – October for Lao PDR; and in March, April, August and September for Viet Nam.

This report contains the assessment of the status, spatial and temporal trends of 17 stations along the Mekong River and 31 stations along the six tributaries, which are classified into Lao PDR's (six stations), Thailand's tributaries (five stations), Sesan, Sekong 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 2024 was compared with the MRC TGWQ Guidelines for the Protection of Human Health and for the Protection of Aquatic Life. Annual spatial analyses of key water quality indicators were performed to identify their instream concentration changes in space. The key water quality indicators include pH, electrical conductivity (EC), total suspended solids (TSS), nitrate-nitrite (NO_{3-2}), ammonium (NH_4N), total nitrogen (TOTN), total phosphorus (TOTP), dissolved oxygen (DO), chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Analysis of temporal trend at each station using monthly data was carried out to determine its trend since it was monitored until 2024. The temporal analyses focused on NO_{3-2}, NH_4, TOTN and TOTP. Potential transboundary water quality issues were also examined for nutrient parameters (NO_{3-2}, NH_4N, TOTN, and TOTP), DO and COD at three 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 2024 were one-way analysis of variance (ANOVA), Seasonal Mann-Kendall and independent T-test. Pearson's correlation was also performed for water quality data in 2024 to understand the relationships among key water quality parameters. The MRC

WQIs were used to quantitatively assess the suitability of water quality conditions for protecting human health, aquatic life and various agricultural uses.

The results of 2024 water quality monitoring data at 48 stations indicated that 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).

WQI for the Protection of Aquatic Life indicated a “good” or “high” rate at 45 out of 48 stations in the LMB. The WQI for the Protection of Human Health, 46 out of 48 stations were rated “good” or “excellent”. The WQI for Agriculture Use rating was “no restriction” and “suitable” for general and paddy rice irrigation, respectively, at all stations in 2024, except for My Tho station, which was seriously impacted by the saline water intrusion in the dry season.

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 on determining the causes of potential transboundary water quality issues at these transboundary sites as soon as possible.

In 2024, according to the MRC WQIs, the water quality was rated stable, at “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, the identification of the water quality issues and instruction through WQMN in responding to these impacts is crucial for continuing the maintenance of “acceptable/good” water quality rating in the Mekong River and its key tributaries.

1. INTRODUCTION

1.1 BACKGROUND

Ranked as 12th longest at about 4,880 km and 8th in terms of mean annual discharge at its mouth at about 14,500 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 an area downstream of the Chinese border with Lao PDR.

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

According to the 2023 State of the Basin Report (MRC, 2024), the Lower Mekong River is home to about 69 million people, of whom about 85% live in rural areas where many practise subsistence farming, with supplemental fish catch for livelihoods and food security. The Mekong River is also one of the most biodiverse rivers in the world with estimated 1,148 fish species (MRC, 2019). The river's annual flood pulse continues to support a rich natural fishery and an extensive and unique wetland environment. This makes the rich ecology of the Basin extraordinarily important in terms of its contribution to livelihoods and sustainable development. As such, water quality monitoring is an integral part of detecting changes in the Mekong riverine environment and for maintaining good/acceptable water quality to promote the sustainable development of the LMB.

1.2 WATER QUALITY MONITORING NETWORK AND THE PROCEDURES FOR WATER QUALITY

1.2.1 WATER QUALITY MONITORING NETWORK

Recognizing that sustainable development of water resources of the LMB will not be possible without effective management of water quality, the MRC Member Countries (MCs) agreed to establish a Water Quality Monitoring Network (WQMN) in 1985 with the specific objectives of monitoring the status and detecting changes in the Mekong River water quality and ensuring preventive and remedial actions are taken if any changes are detected. Between 1985 and 1992, the WQMN comprised 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. In 2024, water quality is monthly monitored at 17 stations along the Mekong mainstream and 31 stations in the tributaries of the Mekong River (see Section 2, Table 2.2) with 19 parameters. The WQMN is implemented by a designated national laboratory in each MCs (Table 1.1).

Table 1.1. Designated National WQMN in 2024

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

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

1.2.2 Procedures for Water Quality

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

To support the implementation of the PWQ, MCs have jointly developed and adopted the Technical Guidelines on the Implementation of the Procedures for Water Quality (TGWQ) consisting of two main parts dealing with the management of water quality (Part A) and framework for responding to water quality emergency incident (Part B). Since its adoption, the implementation of Part A of the TGWQ has been through the implementation of the WQMN. The first part of the TGWQ provides systematic guidelines for the management of

water quality for the protection of human health (Chapter 1) and the protection of aquatic life (Chapter 2); MCs have integrated these guidelines into the routine activities of the WQMN, including the adoption of methods for field sampling, laboratory analysis and data assessment that ensure the comparability of the monitoring data.

Chapters 1 and 2 aim to provide decision support tools *for the management by the MCs 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. For Chapter 1, water quality criteria are grouped into two types (direct impact parameters and indirect impact parameters) depending on their characteristics and their potential effects on human health (Tables 1.2 and 1.3).

Table 1.2. 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	3,550-As/SM
2	Cadmium	Cd	mg/l	0.005[(2)]	3,110-Cd/SM
3	Chromium hexavalent	Cr	mg/l	0.05	3,550-Cr/SM
4	Cyanide	CN	mg/l	0.01	4,500-CN/SM
5	Lead	Pb	mg/l	0.05	3,110-Pb/SM
6	Total mercury	Total Hg	mg/l	0.002	3,112-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	5,530-Phenol/SM
9	Total organochlorine pesticide		mg/l	0.05	6630-organochlorinePesticides/SM
10	Faecal coliforms		MPN/100 ml	1,000[(3)]	9,221E-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 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 MRCS, will continue to study this issue in order to reconsider the interim target value.

Table 1.3. 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)]	4,500-NH_3/SM
2	Biological oxygen demand	BOD_5	mg/l	4	5,210-BOD_5/SM
3	Chemical oxygen demand	COD_{Mn}	mg/l	5	$KMnO_4$ method
4	Conductivity	EC	mS/m	70-150	2,510-EC/SM
5	Dissolved oxygen	DO	mg/l	≥ 6[(3)]	4,500-O/SM
6	Total nitrite and nitrate as N	(NO_2 + NO_3) as N	mg/l	5	4,500-NO_3/SM
8	pH	pH		6-9	4,500-H^+/SM
9	Temperature	T	°C	Natural	2,550-Temp/SM
10	Total coliform		MPN/100ml	5000	9,221-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 MRCS, 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 MRCS will continue to study this issue in order to reconsider the interim target value.

Water quality criteria for Chapter 2 are grouped into two types – 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 1.4).

Table 1.4. Water quality criteria for the protection of aquatic life (direct impact parameters) (No. 1 to 10) and environmental stressor parameters (No. 11 to 18)

No	Parameters Name	Symbol	Unit	Value	Analytical method[1]
1	Arsenic	Total As	mg/l	0.01	3,550-As/SM
2	Cadmium	Cd	mg/l	0.005[2]	3,110-Cd/SM
3	Chromium hexavalent	Cr (VI)	mg/l	0.05[3]	3,550-Cr/SM
4	Copper	Cu	mg/l	0.1	
5	Cyanide	CN	mg/l	0.005	4,500-CN/SM
6	Lead	Pb	mg/l	0.05[4]	3,110-Pb/SM
7	Total mercury	Total Hg	mg/l	0.001[5]	3,112-Hg/SM
8	Oil and grease[6]	***Should not occur in such a way that:*** • it can be observed as an oil film, sheen or discolouration; • one can smell its odour; or • it can be seen as oily deposits on the river bank and/or at the river bottom.			Observation
9	Phenol	C_6H_5OH	mg/l	0.005	5,530-Phenol/SM
10	Total organochlorine pesticide		mg/l	0.05	6,630-Organochlorine pesticides/SM
11	Ammonia	NH_3 as N	mg/l	0.2[8]	4,500-NH_3/SM
12	Biological oxygen demand	BOD_5	mg/l	3[7]	5,210-BOD_5/SM
13	Dissolved oxygen	DO	mg/l	> 5	4,500-O/SM

14	pH	pH		6–9	4,500-H^+/SM
15	Temperature		^oC	Natural	2,550-Temp/SM
16	Nitrite[9]	NO_2 as N			
17	Nitrate	NO_3 as N	mg/l	5	4,500-NO_2-C/SM
18	Phosphate[9]	PO_4 as P			

(1) If the laboratories use their in-house methods and/or non-standard methods, they have to comply with the requirements of method validation of ISO/IEC 17025-2005

***(2)** When the water hardness is less than 100 mg/l as $CaCO_3$*

(3), (4),(5),(6) and (7)An interim target value requiring further review by the TBWQ. The TBWQ with support from the Mekong River Commission Secretariat will continue to study this issue in order to reconsider the interim target value.

(8) An interim target value requiring further review by the TBWQ. The TBWQ with support from the MRC Secretariat will continue to study this issue in order to reconsider the interim target value. Thailand proposes 0.5 mg/l; Vietnam proposes 0.1 mg/l.

(9) Target values will be proposed in the future when the national standard target values for Lao PDR and Thailand are available.

1.3 OBJECTIVES

The routine water quality monitoring under the WQMN has become one of the key environmental monitoring activities implemented under the MRC Environmental Management Division (ED). Its importance is captured in the MRC Basin Development Strategy for 2021–2030, where two major outputs are expected on an annual basis: annual water quality data and an annual water quality and data assessment report. This report has been prepared in response to these required outputs. It provides the consolidated results from the water quality monitoring activities of the MCs, focusing on the compliance of water quality data with target values established in the TGWQ for the protection of human health and aquatic life, as discussed in Section 1.2.2 (Tables 1.2, 1.3 and 1.4). As such, the main objectives of this report are:

- Provide the status of water quality in the Mekong River in 2024 by assessing water quality monitoring data monitored by the WQMN laboratories in 2024 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 2024.
- 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 2024.
- Assess the suitability of the Mekong River's water quality for the protection of human health, the protection of aquatic life and/or to support the productivity of the agricultural activities in the LMB; and
- Provide recommendations for future monitoring and continuous improvement of the water quality monitoring activities in the LMB.

2. MATERIALS AND METHODS

2.1 MONITORING LOCATIONS AND FREQUENCY

Forty-eight stations were monitored by the WQMN in 2024 (Tables 2.1 and 2.2) located in the Mekong mainstream and its tributaries (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 13th and 18th day of each month.

Table 2.1. A summary of 2020 water quality monitoring stations

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

Table 2.2. The 48 stations monitoring water quality in 2024

Station (abbr.)	WQMN Station ID	Station names	River names	Country	Latitude	Longitude
LHK	H010500	Houa Khong	Mekong River	Lao PDR	21.5471	101.1598
TCS	H010501	Chiang Sean	Mekong River	Thailand	20.2674	100.0908
LBK	H100101	Ban Hatkham	Nam Ou River	Lao PDR	20.0850	102.2522
LLP	H011200	Luang Prabang	Mekong River	Lao PDR	19.8928	102.1342
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

Station (abbr.)	WQMN Station ID	Station names	River names	Country	Latitude	Longitude
VTB	H988316	Tinh Bien	Vinh Te Canal	Viet Nam	10.8253	105.3367
VMH	H019804	My Thuan	Mekong River	Viet Nam	10.8044	105.2425
VCT	H039803	Can Tho	Bassac River	Viet Nam	10.7064	105.1272
VMT	H019805	My Tho	Mekong River	Viet Nam	10.6039	104.9436
VBD	H451303	Ban Don	Sre Pok River	Viet Nam	10.5206	105.8458
VPC	H440202	Pleicu	Se San River	Viet Nam	10.4361	105.0553
VTH	H988115	Thong Binh	Thong Binh Canal	Viet Nam	10.3431	106.3506
VTT	H988114	Tu Thuong	Tu Thuong Canal	Viet Nam	10.2725	105.9100

Denotes mainstream stations

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

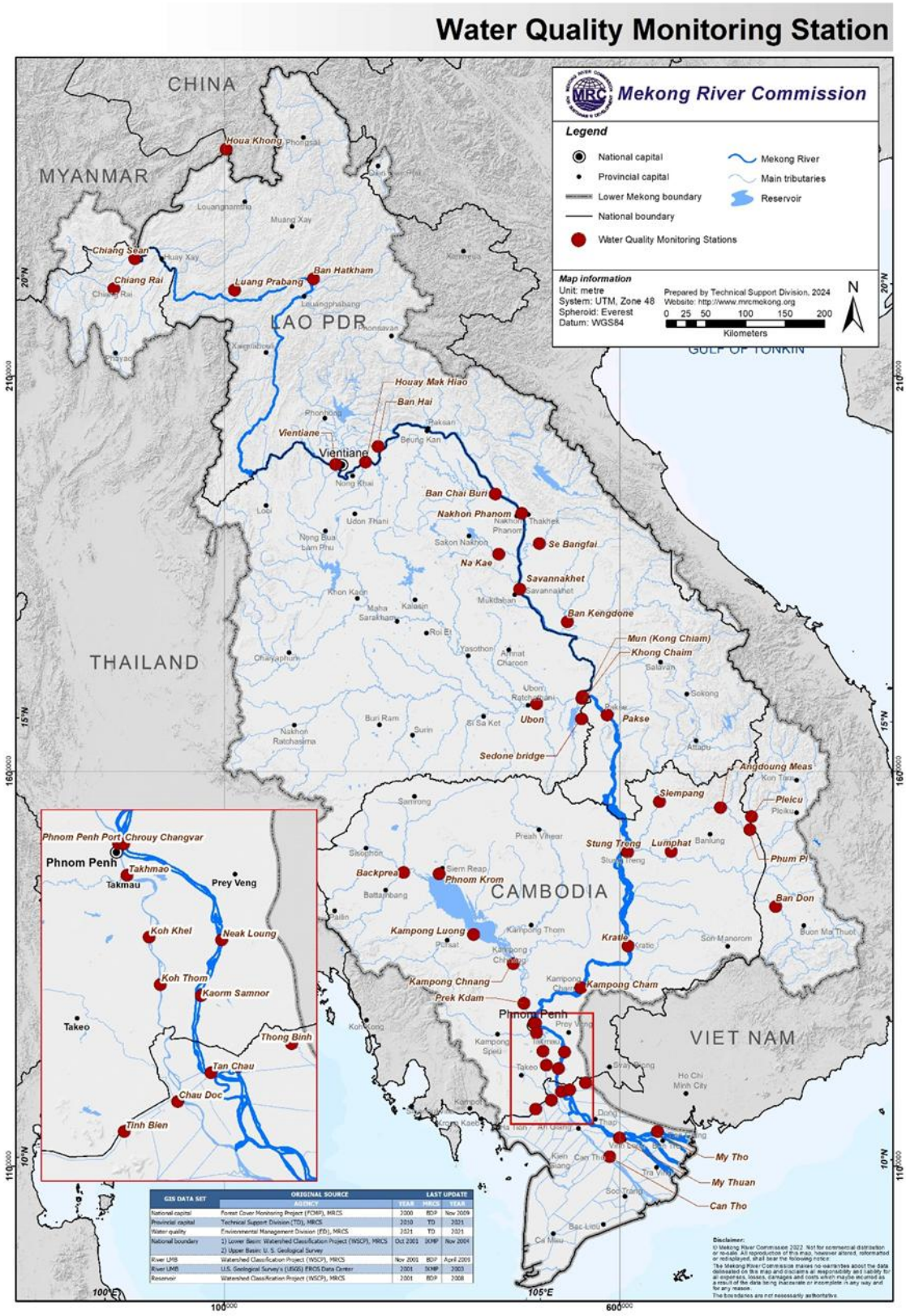


Figure 2.1. Spatial distribution of the 48 primary water quality stations monitored by the WQMN, 2024

2.2 SAMPLING TECHNIQUES

In 2024, the water quality sampling and sample preservation, transportation and storage were conducted according to the methods listed in the TGWQ (Section 1.2.2) or with national standards complying with the requirements of method validation of ISO/IEC 17025-2017. 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 proper preservative agents (i.e. sulphuric acid for nutrients measurement) and store in a cooler to prevent further breakdown of chemicals and biological contents; and
- analyse all water samples within the recommended holding time.

All designated laboratories of the MRC WQMN are required to adhere to the MRC quality assurance/quality control (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

In 2024, 19 water quality parameters were measured (Table 2.3). Of these parameters, 13 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 ($NO_{2\text{-}3}$)	4500-$NO_{2\text{-}3}$/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 2024, water quality was assessed according to Figure 2.2, which 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, which consist in: the assessment of water quality status in 2024; the spatial of assessment of changes in 2024; 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 **Annex A**, and summarized as follows:

- the evaluation of the status of the Mekong River's water quality recorded in 2024 (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);

[1] Member Countries (MCs) 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.

- 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 2024 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 (Section 2.4.1).

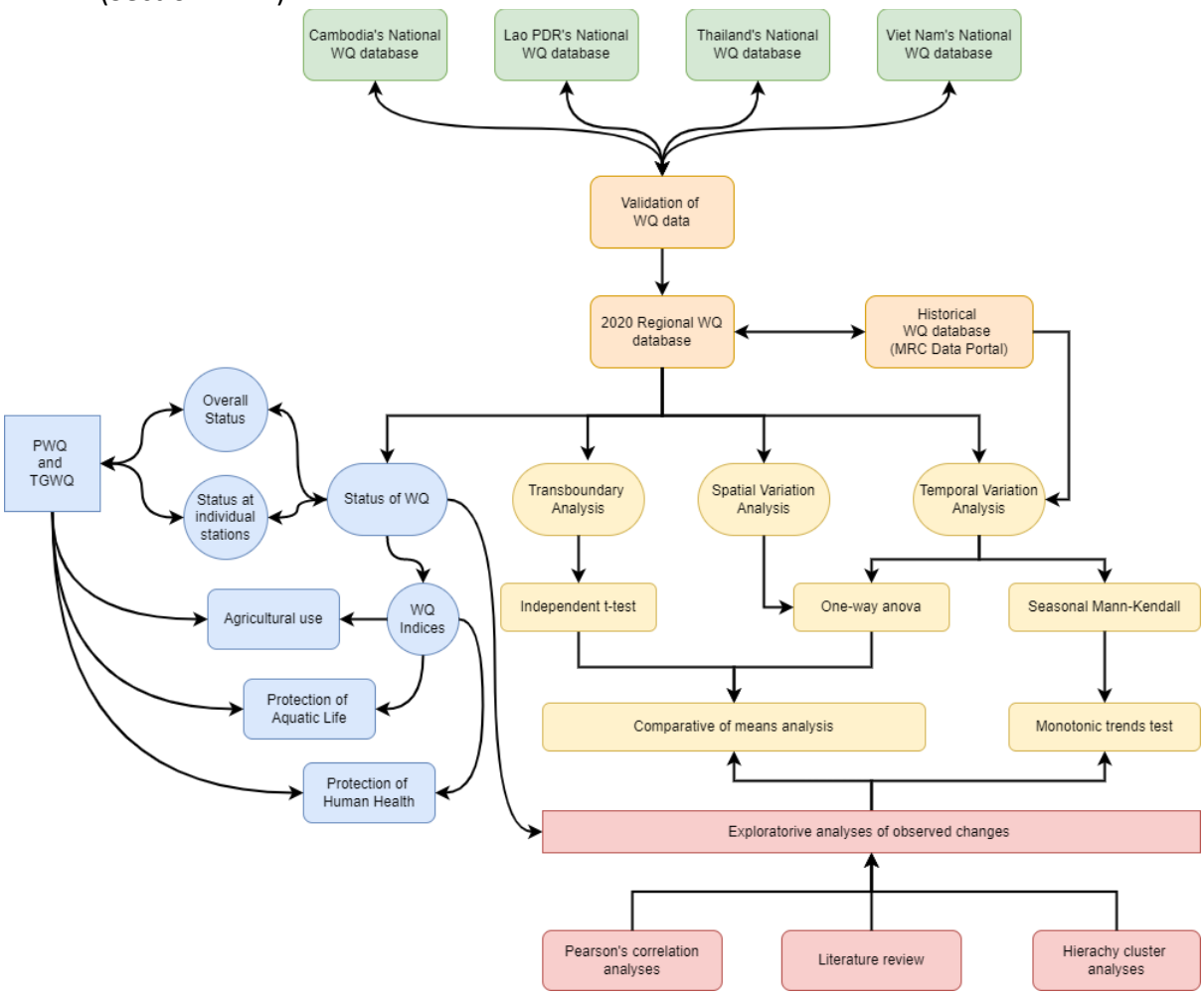


Figure 2.2. The approaches used for the analyses of 2024 water quality data to support the identification of water quality status and spatiotemporal variation

3. RESULTS

3.1 STATUS OF THE MEKONG WATER QUALITY IN 2024

In 2024, 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 3,335 data points for the 17 stations located in the Mekong mainstream; 972 data points for the 5 Bassac River stations; and 5,003 data points for the 26 tributary stations, which are Lao PDR's tributaries (six stations, 1,139 data points), Thailand's tributaries (five stations, 1,140 data points), Sesan, Sekong and Srepok (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 2024 water quality status were assessed separately for mainstream and tributaries stations against the objectives of the MRC PWQ 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 MRC MCs for Chapter 1 (WQGH) and Chapter 2 (WQGA) of the TGWQ.

Using a commonly applied descriptive statistical analyses (Section 2.4), 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 timeseries data, water quality timeseries 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" compared to the established target values (Fu & Wang, 2012; Von Sperling, Verbyla, & Oliveria, 2020). The status of water quality in the Mekong mainstream and its tributaries in 2024 is discussed separately in Sections 3.1.1 and 3.1.2.

3.1.1 Mekong Water Quality in 2024

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 the water quality of the Mekong River in 2024 was generally of moderately good quality. There were seven water quality parameters that were observed in at least one sample out of the target values of WQGH and WQGA – pH, electrical conductivity (EC), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), ammonium (NH_4-N) and faecal coliform (FC). Of the remaining four parameters (TSS, NO_{3-2}, TOTN and TOTP) used as proxies for water quality in this report, data for NO_{3-2} were well within their target values of WQGH (at all 17 stations) (Table 3.1).

Of the seven water quality parameters with one or more data points exceeding their respective target values of WQGH and WQGA, EC values were found to have most of the data points lower than 70 mS/m. The highest EC was observed at My Tho station in March 2024, at 525 mS/m, which is beyond the EC target range of 70–150 mS/m. At this station, the high EC beyond the target range was also detected in February and April, which were 172.8 mS/m and 320 mS/m, respectively. The high EC observed at My Tho station reflected the extreme

salinity intrusion in the Delta in the dry season of 2024, which was more serious with respect to 2023. The lowest EC (10.19 mS/m) was recorded at Savannakhet station (LSV) in December 2024.

In 2024, FC continued to impair the water quality of the Mekong River. Nearly 33% of FC samples (55/167) exceeded the WQGH target value (1,000 MPN/100 ml), which slightly increased compared to 2023 water quality data (31% or 51/165 FC samples). The stations where FC values were exceeded the WQGH target value were Kampong Cham (CKC, 12/12 months), Chroy Chanvar (CCC, 12/12 months), Neak Loeung (CNL, 12/12 months), Chiang Saen (TCS, 5/12 months), Nakhon Phanom (TNP, 9/12 months), My Tho (VMT, 4/12 months) and Tan Chau (VTC, 1/12 months). The highest FC value was recorded at CCC (in May, August and September) and CNL (in August), at 27,000 MPN/100 ml. Compared to 2023, the mean FC at CCC was significantly increased in 2024, i.e. from 4,150 MPN/100 mL to 10,817 MPN/100 mL. For all the mainstream stations, the average FC in the mainstream was 2,254 MPN/100 ml. The average FC showed a higher value in the wet season than in the dry season, which was 2,947 MPN/100 mL compared to 1,581 MPN/100mL, indicating the seasonal variation of the FC contamination in the Mekong River. In addition, most of the stations monitoring FC are located in the main cities and towns along the Mekong River, where the sources possibly come from human waste discharged to the river by stormwater or overflow water and wastewater coming from unsafely managed sanitation (Eliyan et al., 2022). Therefore, the actions and solutions for the faecal contamination should be necessarily considered and assessed, especially in the cities and towns of the Mekong River corridors.

COD and BOD values ranged from 0.07 mg/L to 9.21 mg/L, and 0.04 mg/L to 4.18 mg/L, respectively. Exceeded threshold values of WQGH (5 mg/L) were recorded for COD at Chiang Saen (TCS) and Nakhon Phanom (TNP) from July to October (no data of TCS in September due to the flooding period), at Khong Chiam (TKC) in August and September, at VMT in February and April, at My Thuan (VHM) in January, June, and from September to December, and at Tan Chau (VTC) in June, October and December. The highest COD was 9.21 mg/L and recorded at TKC in September, which was the time the flooding occurred in the upstream of the LMB due to the heavy rain after Typhoon Yagi hit Viet Nam. This indicated the impact of flooding on the water quality in the Mekong River, especially at the cities and towns along the Mekong River corridor, where floodwater rapidly mixed with the pollutants from different sources (e.g. storm run-off, sewage, wastewater, leachate from landfills, fertilizers, animal waste and crop residue), causing a significant increase in COD. Although high COD was observed at stations in Thailand and Viet Nam, the average value of COD in the mainstream was below the WQGH, at 2.54 mg/L, which was not much different from that in 2023 (2.57mg/L). The average BOD of the mainstream stations was also below the WQGH (4 mg/L) and WQGA (3 mg/L), at 1.41 mg/L. This value is slightly higher than that in 2023, which was 1.21 mg/L.

With regard to DO, only 3 % of water samples were below the target values of WQGH (6 mg/L). Compared to 2023, the DO values that did not meet the target values of WQGH (6 mg/L) were continuously decreased from 6% to 3% of the samples. In addition, all DO values were well above the target value of WQGA (5 mg/L). This result maintained the improvement of water in the mainstream observed in 2023, according to the DO.

In 2024, the pH was once observed to be lower than the low target value of WQGH and WQGA (6) at VMT in February and twice in Savannakhet (LSV) in October and November. The low pH in VMT may be related to the effects of acid sulphate soil when it is exposed to the surface during the dry season. In Savannakhet, the pH less than 6 is rarely observed according to the historical data at this station, whose average pH is 7.43 in 1993–2023. Since the low pH may affect the fisheries, which are sensitive to the change of pH, the cause of low pH observed at LSV needs to be identified. The highest pH was recorded at Houa Khong station (LHK) in July, at 8.6. In comparison to 2023, the pH in the mainstream was stable and maintained, which was 7.30 in 2024 compared to 7.33 in 2023, on average.

Table 3.1. Status of Mekong River water quality data as monitored in 2021 and compared to historical record

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	0.50	-	-	≥ 6	5.00	1,000	4.00
	Chapter 2 (WQGA)		6 – 9	-	-	5.00	-	-	-	5.00	-		3.00
2024	Dry season	Mean	7.37	30.46	41.79	0.22	0.07	0.38	0.07	7.27	2.21	1,581	1.46
	Wet season	Mean	7.23	139.57	23.56	0.25	0.05	0.44	0.12	7.00	2.86	2,947	1.35
	Total	Max	8.60	674.00	525.00	1.12	1.33	2.51	0.38	10.13	9.21	27,000	4.18
		Mean	7.30	84.74	32.72	0.23	0.06	0.41	0.10	7.14	2.54	2,259*	1.41
		Min	5.56	1.80	10.19	0.02	0.00	0.06	0.00	5.65	0.07	4	0.04
		Std. deviation	0.50	129.57	7.92	0.21	0.08	0.36	0.07	0.68	1.91	4,864	0.84
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	1,353*	1.21
		Min	5.87	2.80	11.70	0.01	0.00	0.05	0.01	5.04	0.38	BLD	0.49
		Std. deviation	0.44	63.34	7.92	0.22	0.08	0.34	0.10	0.68	1.67	11,763	0.86
Historical	Total	Max	9.94	5,716.00	841.00	2.19	2.99	4.89	2.20	13.85	65.00	240,000	7.47
		Mean	7.48	129.58	21.45	0.25	0.05	0.57	0.09	7.16	2.29	4,191*	1.23
		Min	3.78	0.10	1.20	0.00	0.00	0.00	0.00	0.00	0.00	BLD	0.00
		Std. deviation	0.50	234.17	28.54	0.10	0.10	0.40	0.11	1.08	1.90	11,206*	0.94

* The average was calculated by excluding abnormal values higher than 100,000 MPN/100 ml.

Note: Yellow indicates non-compliance with WQGH or WQGA.

BLD: below limit detection.

3.1.2 Water Quality of Tributaries in 2024

Table 3.2 provides a descriptive statistical summary of key water quality parameters of the Mekong River tributaries in 2024. For this report, the stations of the tributaries of the Mekong River are grouped as follows:

- the 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 2024, water quality of tributaries showed similar characteristics of the mainstream of the Mekong River. In the tributaries, pH values less than 6 were observed at Se Bangfai (LSB, in May, August and October) and Ban Kengdone (LBK, in May, September and October) stations in Lao tributaries, while the others were in the range of the target values of WQGA and WQGH (6–9, Table 3.2). The lowest pH was 5.41 detected in August at LSB, the tributary in Lao PDR. The highest pH was observed at Houay Mak Hiao in May (LHM, Lao tributaries), at 9.03, which was higher than the upper pH target value in the range of 6–9 for WQGH.

In all tributaries, the NO_{3-2} concentrations were low and below the threshold value of 5 mg/L for WQGA and WQGH (Table 3.2). 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 and in the target range in the remaining months. The highest mean EC was at Lao PDR's tributaries (30 mS/m). The mean EC values at the other tributaries were as follows, in ascending order: 3S river system, Tonle Sap river system, Thailand's tributaries, Bassac River and Viet Nam's Delta (6.77, 14.1, 18.8, 22.7 and 27.0, respectively). The lowest EC value was 4.69 mS/m in November at VPC (3S Basin), and the highest EC was 143 mS/m in February at LHM (Lao PDR tributary).

For FC, the values ranged from 3 MPN/100 ml to 42,000 MPN/100 ml. The highest FC was 42,000 MPN/100 ml, detected in May 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, Viet Nam's Delta and Lao PDR's tributaries were 30% (18/60), 54% (26/48), 3% (1/36) and 6% (4/72), respectively. At CPP, which is the station monitoring FC in the Tonle Sap river system, all the samples exceeded the target value of WQGH (1,000 MPN/100 mL). It should be noted that CPP is located close to Phnom Penh Port;

hence, the exceedance of FC mainly related to pollution from human activities. However, no sample showed an exceedance of FC according to the target value of the WQGH in the 3S river system. In Thailand's tributaries, exceeded FC values were observed at TCR (9/12 samples), TNK (2/12 samples) and TUB (7/12 samples). The exceeded FC values ranged from 1,300 MPN/100 mL to 16,000 MPN/100 mL, and the highest value was at TCR (16,000 MPN/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 2,200 MPN/100 ml to 42,000 MPN/100 ml. For Bassac River stations in Viet Nam, exceeding values of FC were detected once in July at VCT, at 4,300 MNP/100 ml. In Viet Nam's Delta, one sample recorded a FC value higher than WQGH (1,000 MPN/100 mL) at Tu Thuong (VTT), at 2,300 MPN/100 ml.

Regarding COD, the highest concentration was 51.12 mg/L in September at Chiang Rai (TCR) of Thailand's tributary when the high flooding occurred in the upstream of LMB. At this station, 50% (6/12 samples) of the samples exceeded the WQGH target value (5 mg/L). The mean COD in the tributaries were 1.15, 2.18, 3.47, 3.72, 4.63 (excluding the abnormal value of 51.12 mg/L) and 4.91 mg/L. 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), two exceeded values were recorded in LMK (Lao PDR's tributaries. In addition, 4.4% of total BOD samples (9/204) in tributaries exceeded the threshold values of WQGA (3 mg/L).

Regarding DO, water samples sporadically showed values lower than the target value of WQGH (6 mg/L) at all tributaries, with 20% of samples. With regard to WQGA (5 mg/L), 3.2% of samples had DO values lower than 5 mg/L, which was recorded in Lao PDR's tributaries and Thailand's tributaries. In 2024, the DO of tributaries maintained the good condition observed in 2023. Specifically, the average DO of all tributaries in 2024 and 2023 were 6.60 mg/L and 6.59 mg/L, respectively.

Table 3.2. Water quality status of key tributaries of the Mekong River in 2024

Periods	Statistical Parameters	pH	TSS (mg/L)	EC (mS/m)	NO_{3-2} (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ	Chapter 1 (WQGH)	6 – 9	-	70 150	5	-	-	-	≥ 6	5	1000	4
	Chapter 2 (WQGA)	6 – 9	-	-	5	-	-	-	5	-		3
Lao PDR's Tributaries	Max	9.08	495	143.00	1.56	0.75	2.42	0.22	7.65	9.76	1,300	4.06
	Mean	6.92	55	30.00	0.38	0.06	0.60	0.08	5.99	3.47	294	2.29
	Min	5.41	2	7.30	0.05	0.01	0.16	0.01	2.93	0.64	33	0.10
	Std. Deviation	0.67	92	30.34	0.23	0.10	0.40	0.06	0.90	1.57	277	1.16
Thailand's Tributaries	Max	8.35	2,173	54.32	0.54	0.17	2.09	0.67	9.03	51.12	16,000	2.70
	Mean	7.65	94	18.79	0.21	0.05	0.53	0.08	6.89	4.63*	1,803	1.22
	Min	7.11	1	6.82	0.00	0.00	0.06	0.01	2.94	1.48	9	0.00
	Std. Deviation	0.27	313	10.81	0.16	0.05	0.42	0.11	1.33	6.34	3,744	0.59
3S River System	Max	7.52	226	11.60	1.08	0.19	2.37	0.41	8.50	4.45	230	2.36
	Mean	7.12	45	6.77	0.20	0.05	0.37	0.09	7.32	1.55	18	2.06
	Min	6.68	2	4.69	0.02	0.00	0.05	0.01	5.36	0.30	0	1.78
	Std. Deviation	0.20	56	1.56	0.27	0.03	0.46	0.07	0.64	1.34	47	0.16
Tonle Sap Basin	Max	7.80	1051	26.1	0.37	0.34	0.67	0.65	7.70	4.60	11,000	1.45
	Mean	7.29	126	14.1	0.18	0.18	0.40	0.27	6.90	2.18	4,958	1.03
	Min	6.88	8	11.0	0.05	0.06	0.14	0.07	5.60	0.80	2,200	0.65

Periods	Statistical Parameters	pH	TSS (mg/L)	EC (mS/m)	NO_{3-2} (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	COD (mg/L)	FC (MPN/100 mL)	BOD (mg/L)
TGWQ	Chapter 1 (WQGH)	6 – 9	-	70 150	5	-	-	-	≥ 6	5	1000	4
	Chapter 2 (WQGA)	6 – 9	-	-	5	-	-	-	5	-		3
	Std. Deviation	0.24	175	3.36	0.08	0.07	0.15	0.13	0.49	1.04	2,538	0.27
Bassac River	**Maximum**	7.50	155	45.60	0.75	0.84	1.15	0.36	7.50	5.84	42,000	3.18
	Mean	6.97	45	22.74	0.22	0.10	0.43	0.20	6.55	2.95	6,107	1.87
	Minimum	6.36	6	11.00	0.05	0.00	0.14	0.03	5.42	0.75	9	0.70
	Std. Deviation	0.26	43	10.38	0.19	0.12	0.25	0.08	0.49	1.69	9,786	0.69
Viet Nam's Canal	**Max**	7.50	42	51.70	2.18	2.65	6.15	0.62	7.03	6.72	2,300	2.88
	Mean	6.93	23	27.03	0.55	0.26	1.19	0.19	5.93	4.91	193	2.35
	Min	6.43	5	12.90	0.07	0.00	0.30	0.05	5.02	4.29	3	1.90
	Std. Deviation	0.22	11	11.40	0.46	0.52	1.12	0.14	0.45	0.47	391	0.25

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

3.2 CORRELATION BETWEEN KEY WATER QUALTY PARAMETERS

A correlation between key water quality parameters monitored in 2024 was established for the Mekong River mainstream and its tributaries (Table 3.3, 3.4). This is important to understand the instream behaviours of key water quality parameters (Lee et al., 2016; Ly & Metternicht, 2020).

The results of Pearson's correlation indicated that DO was negatively correlated with TOTP, COD and BOD, with a significant P-value of 0.01. This reflects the impact of organic pollution on the DO values in the mainstream in 2024. In contrast, in the tributaries, the inputs of nutrient parameters (NO_{3-2}, NH_4-N, TOTP and TOTN), COD and BOD were the main cause of low DO values, indicated by the negative correlation of DO with those parameters (significant P-value of 0.01).

TSS significantly showed positive correlations with nutrient parameters and COD in the mainstream and tributaries (correlated with NH4-N and TOTP). This explains the high TSS normally observed in the wet season and the month right after the wet season, when the run-off associated with pollutants is discharged to the mainstream and its tributaries. Specifically, run-off discharge to the river with contaminants from wastewater and pollutants from the surface caused an increase of TSS, NH_4N, TOTP and COD, especially in the cities and town of the Mekong River corridor.

Furthermore, pH value clearly showed a negative correlation with NO_{3-2}, NH_4N, TOTN, COD, and BOD in the tributaries (Table 3.4). 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.

Table 3.3. Correlations between key water quality parameters in the Mekong River, as monitored by the WQMN, 2024

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)	-0.057	1									
EC (mS/m)	-0.101	-0.105	1								
NO_{3-2} (mg/L)	.186**	.310**	0.032	1							
NH_4N (mg/L)	-0.064	.198**	0.032	.169*	1						
TOTN (mg/L)	0.066	.304**	-0.014	.831**	.288**	1					
TOTP (mg/L)	-.263**	.397**	0.023	.162*	.354**	.245**	1				
DO (mg/L)	.445**	-0.090	-0.103	-0.009	-0.047	-0.081	-.239**	1			
COD (mg/L)	0.027	.318**	0.122	.680**	-0.080	.581**	.145*	-.239**	1		
FC (MPN/100 mL)	-0.146	0.109	0.038	-0.145	.155*	-0.003	.367**	-0.097	-.221**	1	
BOD (mg/L)	-.204*	-0.076	.230*	.423**	-0.003	.433**	0.118	-.346**	.616**	-.327**	1

** 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, 2024

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)	0.050	1									
EC (mS/m)	-0.095	-0.087	1								
NO_{3-2} (mg/L)	-.261**	0.003	.314**	1							
NH_4N (mg/L)	-0.039	.139**	.148**	.399**	1						
TOTN (mg/L)	-.245**	0.004	.295**	.860**	.550**	1					
TOTP (mg/L)	0.004	.512**	0.044	.340**	.476**	.358**	1				
DO (mg/L)	.228**	-0.078	-.357**	-.417**	-.149**	-.514**	-.178**	1			
COD (mg/L)	-0.101	.175**	.341**	.354**	.214**	.479**	.264**	-.633**	1		
FC (MPN/100 mL)	-0.047	0.008	-0.058	-0.055	0.063	-0.023	0.056	0.078	0.010	1	
BOD (mg/L)	-.328**	-0.020	.376**	.326**	.203**	.420**	.318**	-.444**	.235**	0.042	1

** 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 the Mekong River's water quality varied from indicator to indicator, with statistically significant variations detected by ANOVA for pH, EC, NO_{3-2}, NH_4N, TOTN, TOTP, COD, DO and BOD, at P-values of less than 0.01. In 2024, TSS was the sole key water quality indicator (excluding the major cations and anions due to the different sampling frequencies in each MC) that showed no statistically significant variation (ANOVA P-value of 0.452) on a spatial scale.

Moreover, pH showed a downward trend from upstream to the Delta (Figure 3.1a). Specifically, pH was slightly higher upstream, at 7.63 on average in three stations (LHK, TCS, LLP) and lower in three stations (VTC, VMH and VMT) in the Delta, at an average of 7.17.

DO showed a wide variation along the mainstream. The DO was 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, of which the average DO values in the wet season are lower than those in the dry season, was observed in most of the mainstream stations, except for LPP.

NO_{3-2}, TOTN, COD and BOD showed a similar spatial trend, with their values in the upstream being 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 NO_{3-2} with TOTN, COD and BOD. The trend can also explain that the occurrence of NO_{3-2}, 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 increasing trend of NH_4-N was observed from upstream to downstream. In particular, the average NH_4-N concentration in the wet season was mostly higher than that in the dry season at stations of the mainstream. Moreover, the high NH_4-N was observed at the main towns along the Mekong River, such as Chiang Saen, Nakhon Phanom in Thailand, Kampong Cham, Chroy Chanvar in Cambodia, and My Tho in Viet Nam (Figure 3.2b). A similar observation was recorded for TOTP concentrations with wide variation. (Figure 3.2d).

In comparison to the EC in 2024, the average EC in the downstream in the Delta was the highest among the stations due to the impact of saltwater intrusion during the dry season, especially observed at VMT. The station with the highest average EC was VMT, at 118 mS/m. The spatial trend of average EC was the lowest in the upstream, slightly increased in the middle stream, and was the highest in the lower stream in Viet Nam Delta (Figure 3.1c). The seasonal trend is clearly displayed with the higher EC in the dry season and lower EC in the wet season at all stations.

In addition, FC levels showed variation 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, one station in Thailand (TKC) and one station in Viet Nam (VMH). Three stations that monitored FC in Cambodia (CKC, CCC and CNL) and two stations in Viet Nam (VTC and VMT) recorded FC values exceeding the target values of WQGH (1,000 MPN/100 ml) (Figure 3.3d). The FC also showed a seasonal trend 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 MRC 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 guidelines must be strictly observed (World Health Organization, 2011).

With regard to TSS, although there was no statistically significant spatial variation, TSS showed a difference between the wet and the dry season; specifically, the average TSS in the wet season was 4.58 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. The increased concentrations of nutrient parameters, COD, BOD, and FC observed in the wet season present an issue with respect to water quality. Therefore, actions for controlling the wastewater and waste disposal, together with stormwater or run-off overflow discharged to the river during the wet season are required. Hence, improving waste management in the cities and towns is urgently needed to maintain the good/acceptable water quality of the Mekong River.

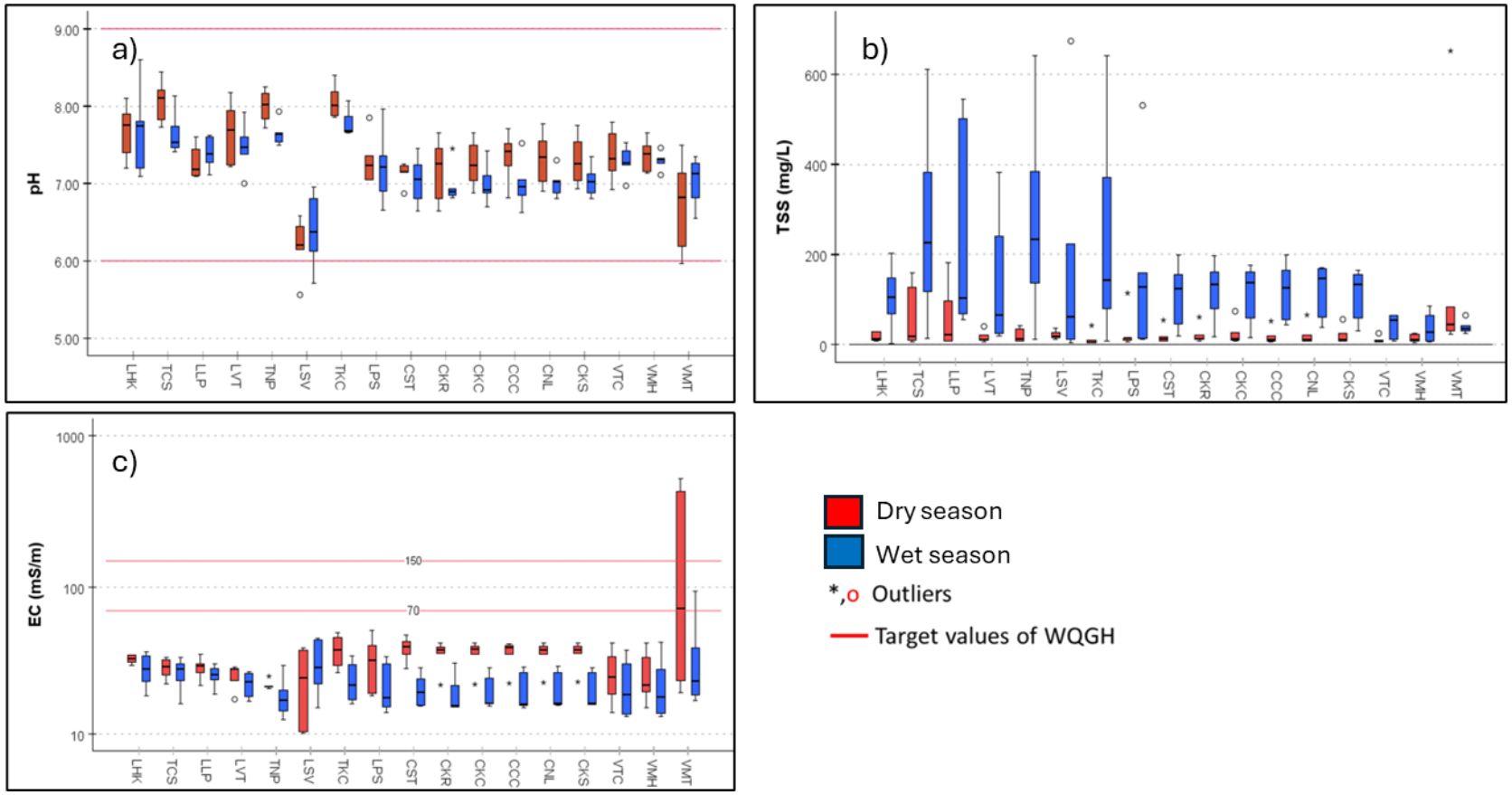


Figure 3.1. Seasonal spatial distribution of (a) pH, (b) TSS levels and (c) EC along the Mekong River, from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)

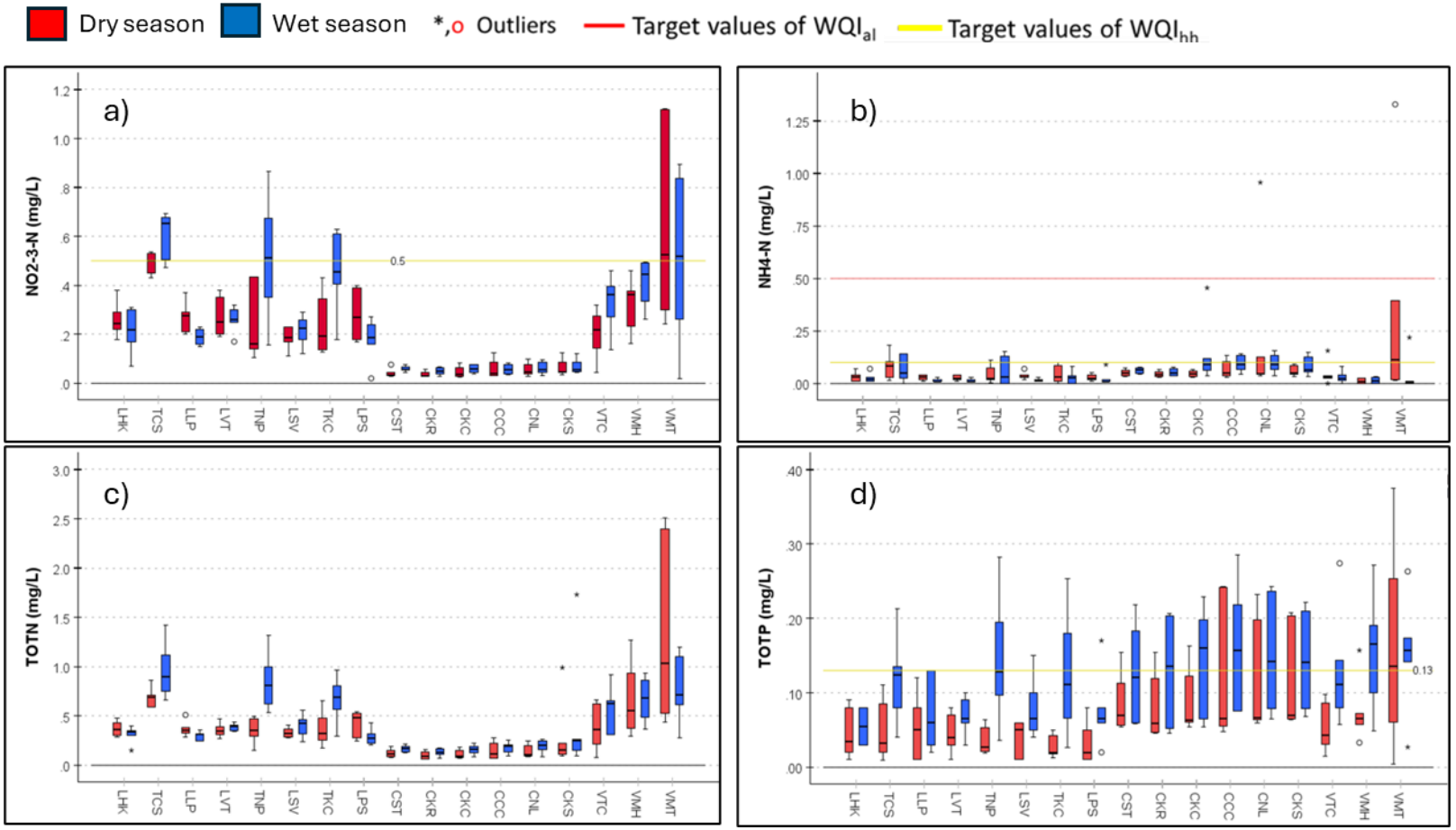


Figure 3.2. Seasonal spatial distribution of (a) NO_{3-2}, (b) NH_4N, (c) TOTN and (d) TOTP levels along the Mekong River, from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)

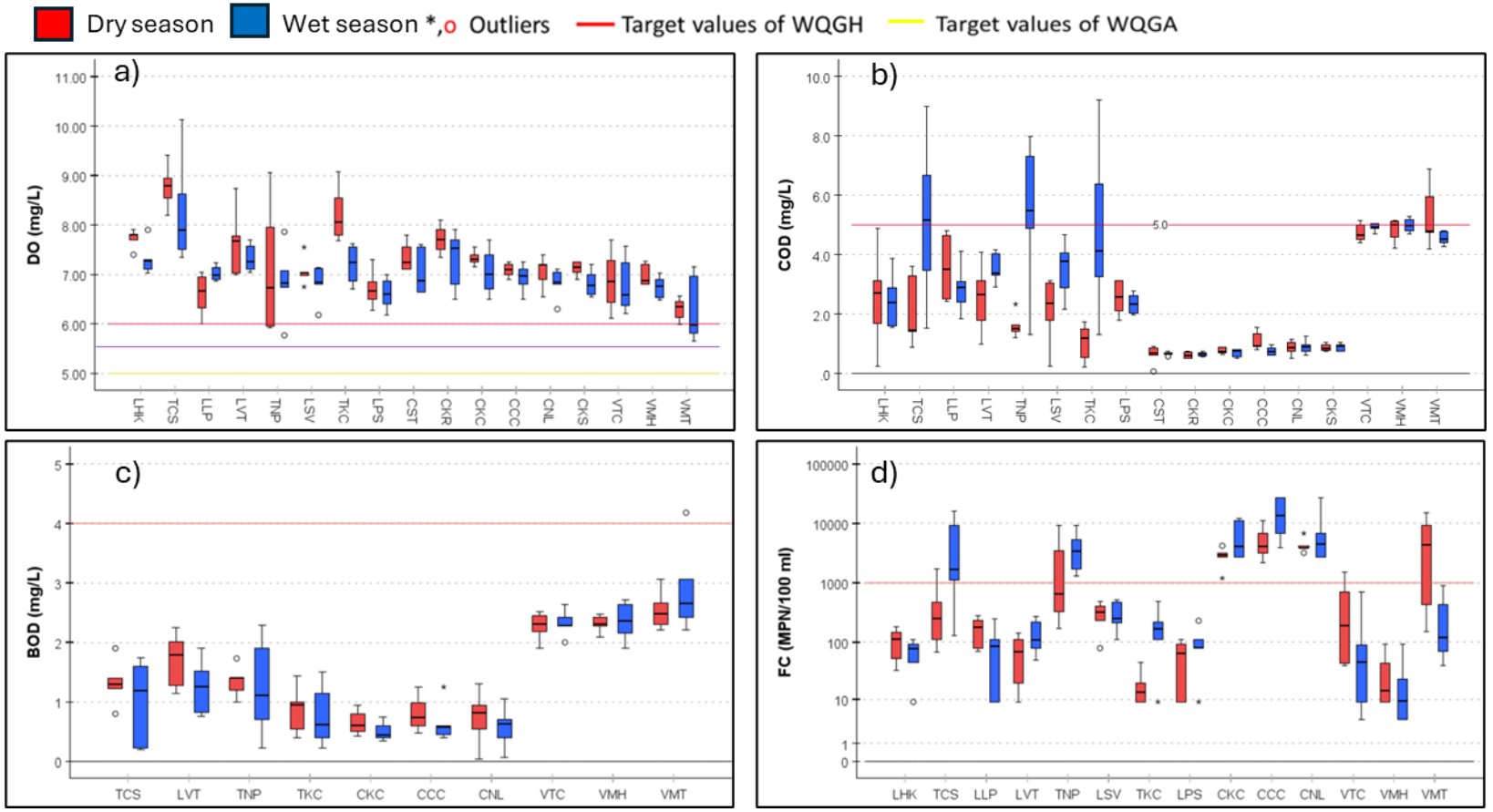


Figure 3.3. Seasonal spatial distribution of (a) DO, (b) COD, (c) BOD, and (d) FC levels along the Mekong River, from the most upstream station (LHK – Houa Khong) to the most downstream station (VMT – My Tho)

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; and
- 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 most of the stations of six tributaries (excepting LSB and LBK in Lao PDR's tributaries); the average pH was the highest in Thailand's tributaries (7.65) and the lowest in Lao PDR's tributaries (Figure 3.4). In each tributary, the pH showed a statistically significant spatial variation in Lao PDR's tributaries, 3S, Bassac River, Tonle Sap 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 was found in LHM (82.8 mS/m, on average), which suggests that agriculture, urbanization and population growth affected 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 at the other stations in Lao PDR tributaries (Figures 3.5 and 3.6). 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. NO_{3-2} and TOTN (except in the Bassac River) showed significant spatial variation in all tributaries. There was no significant spatial variation of NH_4-N in Thailand's tributaries, 3S and Bassac rivers. Regarding TOTP, only the 3S river system showed no significant spatial variation. There were high concentrations of nutrient parameters occasionally observed in the key tributaries, which were associated with a decrease in DO, evidenced by their significant negative correlation of DO with NO_{3-2}, NH_4-N, TOTN and TOTP (Table 3.4). Therefore, it is recommended to closely monitor and conduct further analyses on the sources of increasing nutrient discharge to the river in order to identify risks of water quality issues and proactive action plans. Among the tributaries, NH_4-N exceeding the target value of WQGH (0.5 mg/L) was occasionally observed in Lao PDR's

tributaries, Bassac River and Viet Nam's Delta, with the highest values of 0.75 mg/L, 0.84 mg/L and 2.65 mg/L, respectively, in these tributaries.

Regarding COD, a significant spatial variation was observed in Lao PDR's tributaries, 3S, Bassac, Viet Nam Delta and the Tonle Sap river system. The highest COD was continuously recorded at TCR station of Thailand's tributaries, at 51.12 mg/L in September 2024, when the flood was severe in the upstream of the LMB (see Section 3.1.2). Except for Viet Nam's Delta, DO showed significant spatial variation in the other tributaries. Most of the stations in the key tributaries showed good water quality with respect to DO, although there were some low DO values recorded in the tributaries (Figure 3.4a, Section 3.1.2).

TSS was spatially varied among tributaries. In 2024, the highest TSS was recorded in Thailand's tributaries, at 2,173 mg/L in September at TCR, due to the impact of the high flooding period. The highest average TSS was maintained in the Tonle Sap river system, indicating that the periodical influence of instream and/or bank activities, including inland water navigations and fishery activities (Ang & Oeurng, 2018; Ratha, Grenouillet, & Lek, 2016). However, the water quality in terms of TSS improved downstream of the Tonle Sap river system (Figure 3.4). In each tributary, significant variations of TSS were recorded in Thailand's tributaries and the Tonle Sap river system.

The significant spatial variation of FC was observed in Lao PDR's tributaries, Thailand's tributaries and the Bassac River. The highest FC was 42,000 MPN/100 ml at CTK, in the Bassac river system. Among the tributaries, the FC occasionally exceeded the WQGH (1,000 MPN/100 ml) in Lao PDR, Thailand's tributaries, and more frequently in Tonle Sap, the Bassac river system and Viet Nam's Delta (see Section 3.1.2).

Significantly spatial variations in BOD were found in Lao PDR's tributaries, Thailand's tributaries and the Bassac river system. BOD values exceeding the WQGA (3 mg/L) were recorded in Lao PDR (at LHM) and the Bassac river system (at VCD).

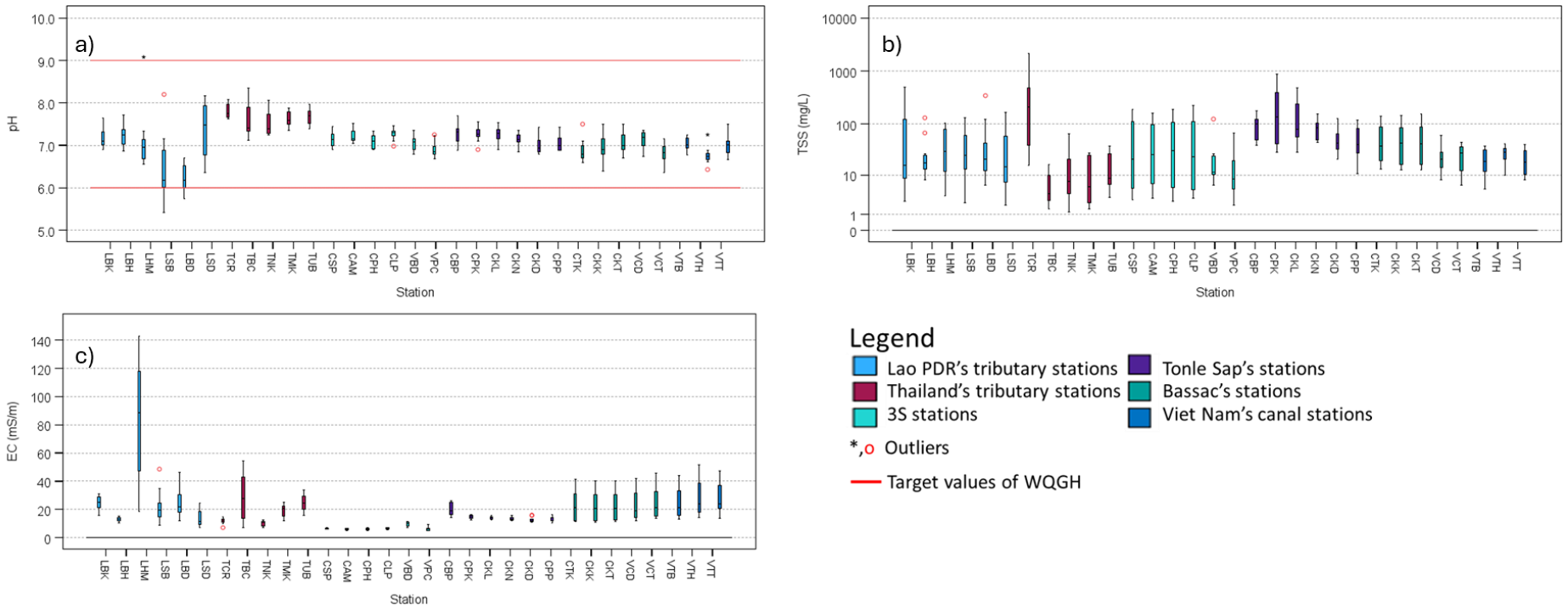


Figure 3.4. Spatial distribution of (a) pH, (b) TSS and (c) EC levels at key tributaries of the Mekong River, 2024

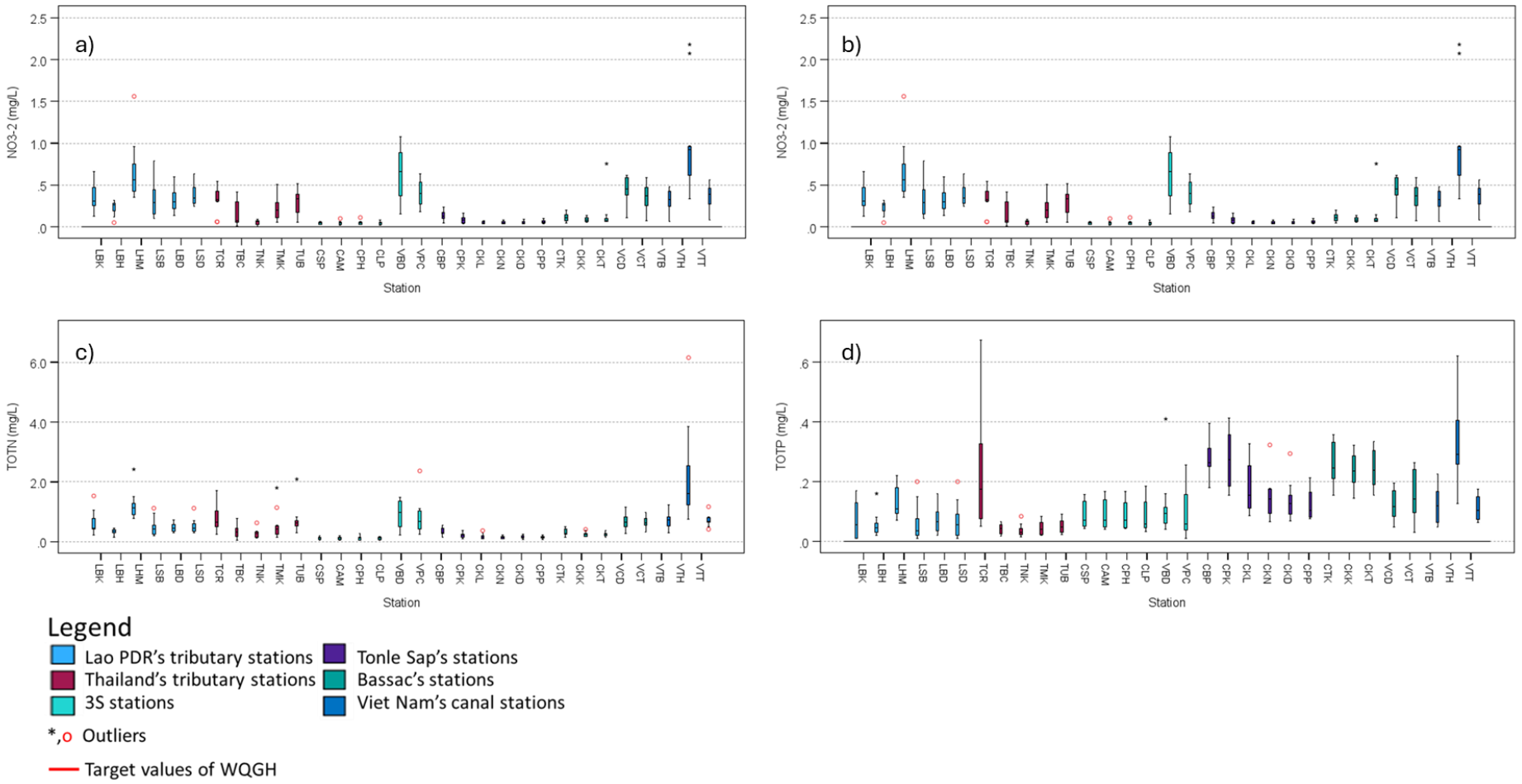


Figure 3.5. Spatial distribution of (a) $NO_{3\text{-}2}$, (b) NH_4N, (c) TOTN, and (d) TOTP levels at key tributaries of the Mekong River, 2024

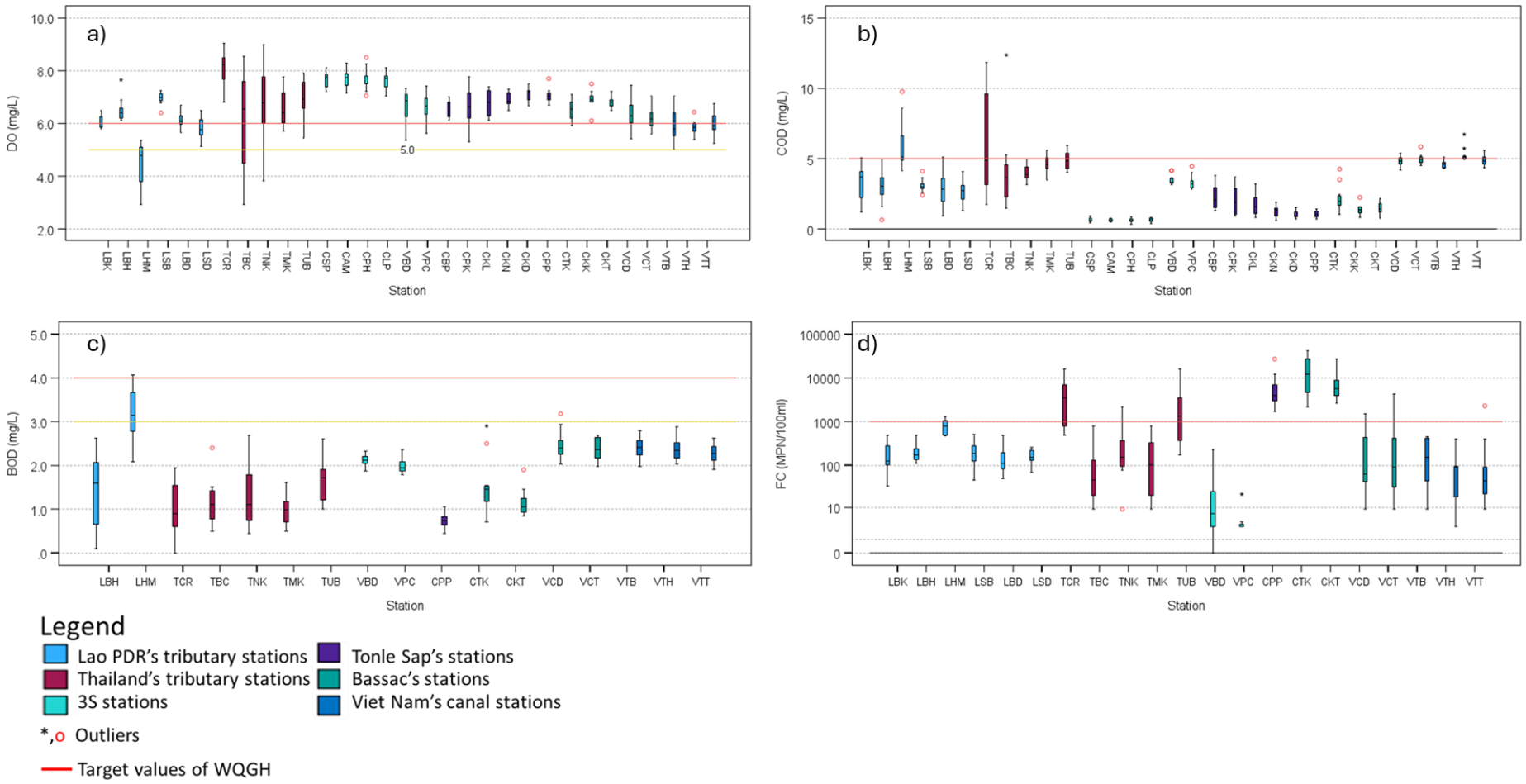


Figure 3.6. Spatial distribution of (a) DO, (b) COD, (c) BOD, and (d) FC levels at key tributaries of the Mekong River, 2024

3.3.2 Temporal variations of water quality

In 2023, the temporal variation of water quality indicated the trend of parameters that exceeded the target values of WQGH and WQGA, which are EC, DO and COD. The temporal trend of these parameters was analysed for each station in the mainstream and tributaries of the LMB (see Annex D of MRCS, 2024). In the 2024 report, the temporal variation focused on the nutrient parameters, which may have impaired the water quality based on the negative correlation with DO (low DO is mostly associated with high nutrient levels). Their temporal variations are discussed in detail below.

3.3.2.1 Nitrogen parameters (NO_{3-2}, NH4-N and TOTN)

Nitrogen parameters in the river are also key indicators of water quality that can affect both aquatic life and the broader environment. Specifically, the high concentration of nitrogen in river water can cause eutrophication, harming aquatic organisms due to the depletion of oxygen by an algae bloom. The nitrogen parameters monitored in MRC WQMN are nitrite-nitrate (NO_{3-2}-N), ammonia (NH_3 or NH_4-N) and total nitrogen (TOTN). These parameters are among the key parameters used for the assessment of WQI for the protection of human health and aquatic life.

The NO_{3-2}-N is a major form of nitrogen in water, of which the sources primarily originate from anthropogenic activities such as agricultural runoff from fertilizer and animal waste, urban runoff carrying pollutants from roads and pavements into rivers, domestic sewage, and point sources of discharges from wastewater treatment plants or industrial facilities. The nitrate contamination in water can cause serious environmental and human health issues. Specifically, high nitrate can impact aquatic life, affecting the reproductive success and health of organisms, disrupting the food webs and ecosystems. It can also impact human health through the consumption of high nitrate concentrations in waterways, such as by causing methemoglobinemia, cancer risk and thyroid disorders. In the Mekong River, the NO_{3-2}-N concentration was from below detection limit to 2.19 mg/L (0.25 mg/L, on average) since it is monitored. The temporal average values of NO_{3-2}-N in tributaries are 0.23 mg/L, 0.15 mg/L, 0.24 mg/L, 0.22 mg/L, 0.27 mg/L and 0.31 mg/L, respectively, in Lao PDR's tributaries, Thailand's tributaries, 3S, Bassac, Tonle Sap Rivers and Viet Nam's Delta. This level indicates that the NO_{3-2}-N is well below the threshold of 5 mg/L for WQGH and WQGA. However, the temporal data of NO_{3-2} indicated a significant increasing trend in most of the stations along the Mekong River and its tributaries. In the mainstream, eight stations show an increasing trend in Lao PDR, Thailand and Viet Nam. A decreasing trend was observed at all stations in Cambodia, one station in Lao PDR (LHK), and one station in Thailand (TCS). No trend was observed at LSV in Lao PDR. In the tributaries, an increasing trend was recorded in all tributaries at 16 stations. The decreasing trend was detected at three stations (one in Thailand and two in the 3S river system). The other stations showed no trend (Annex E). The increasing trend of NO_{3-2}-N may relate to the urbanization and land use change along the Mekong River corridors, which is associated with an increase in nitrate discharges into the rivers. The decreasing trend observed in Cambodia may be due to the denitrification, a microbial process, which reduces NO_{3-2} to nitrogen gas and releases it into the atmosphere (Gomez-Velez et al., 2015).

NH_4-N is primarily from fertilizer, sewage and agricultural runoff. Its high concentration can be toxic to aquatic organisms such as fish and invertebrates. In addition, NH_4-N contributes to eutrophication, leading to algae blooms. The long-term impact of NH_4-N contamination can cause the loss of biodiversity. Moreover, consuming water with high NH_4-N concentrations is a risk to human health, which leads to health issues such as skin irritation and even waterborne diseases. In the Mekong River, the temporal data of NH_4-N showed a range from below detection limit to 2.99 mg/L (0.05 mg/L on average) and rarely higher than the threshold value of 0.5 mg/L for the WQGH. Similarly, in tributaries, the NH_4-N is rarely above the threshold value for the WQGH and ranges from below the detection limit to 3.04 mg/L. In the tributaries, there are stations where NH-N more frequently exceeded the threshold value for WQGH (0.5 mg/L), thus requiring more consideration on the NH_4-N issue, including LHM in Lao PDR's tributaries, CTK in the Bassac River, and VTH in Viet Nam's Delta (Figure 3.8). The temporal average values of NH_4-N in tributaries are 0.07 mg/L, 0.06 mg/L, 0.05 mg/L, 0.08 mg/L, 0.1 mg/L and 0.16 mg/L, respectively, in Lao PDR's tributaries, Thailand's tributaries, 3S, Bassac, Tonle Sap rivers and Viet Nam's Delta. In the mainstream, a significantly increasing trend of NH_4-N was recorded at 10 stations; four stations showed a decreasing trend; and three stations showed no trend (Annex E). In tributaries, 18 stations showed an increasing trend; nine showed a decreasing trend; and four stations showed no trend (Figure 3.8 and Annex E). Among countries, stations with an increasing trend of NH_4-N are mostly located in Cambodia (60% in the mainstream, and 72% in the tributaries). Since the NH_4-N contaminates the river water mostly from the domestic wastewater (Duan et al., 2018), proactive plans for wastewater treatment and improvement of the sanitation system in the cities and towns along the Mekong River are necessary to prevent the degradation of water quality due to NH_4-N contamination. It should also be noted that the NH_4-N can be decreased by the sorption and nitrification when exposed to the surface water. Therefore, more studies are required to determine the sources of NH_4-N in the Mekong River, i.e. applying isotopic technology.

The TOTN in the river is the sum of all forms of nitrogen in the water, including NH_4-N, $NO_{3\text{-}2}$ and organic nitrogen. The presence of TOTN in the river water is controlled by various factors, such as natural processes (nitrogen fixation) and anthropogenic processes (agricultural runoff and wastewater discharges). The high concentration of TOTN in river water can be associated with the harmful effects, like algae blooms, contributing to the loss of oxygen that affects the aquatic life. In the Mekong River, the temporal data indicated a range from below detection limit to 4.89 mg/L (0.57 mg/L on average). In the tributaries, the temporal average values of $NO_{3\text{-}2}$-N were 0.76 mg/L, 0.53 mg/L, 0.46 mg/L, 0.72 mg/L, 0.47 mg/L and 0.90 mg/L, respectively, in Lao PDR's tributaries, Thailand's tributaries, 3S, Bassac, Tonle Sap Rivers and Viet Nam's Delta. In the mainstream, an increasing trend was observed at five stations, while a decreasing trend and no trend were shown at eight and 11 stations, respectively (Annex E and Figure 3.9). All stations in Cambodia indicated an decreasing trend of TOTN. In the tributaries, 13 stations showed an increasing trend; six stations showed a decreasing trend; and 13 stations showed no trend (Annex E and Figure 3.9).

In summary, the temporal data of the nitrogen parameters indicated that, in terms of nitrogen parameters, the water quality is maintaining a good or an acceptable quality in the Mekong River and its tributaries. The trend of nitrogen parameters is not consistent along the Mekong River and in its tributaries, reflecting the impacts of different processes and controlling

factors. Moreover, proactive solutions to prevent and reduce the input of nitrogen sources into the Mekong River and its tributaries should be considered for the locations observed an increasing trend of nitrogen parameters. Specifically, improving wastewater management and wastewater treatment are recommended solutions for reducing nitrogen discharged to the Mekong River and its tributaries.

3.3.2.2 Total Phosphorus

Phosphorus is a key nutrient for the aquatic ecosystem. However, the excess of phosphorus can cause a negative impact on the water quality and the ecosystem, such as eutrophication. The total phosphorus (TOTP) in the river water expresses the various forms of phosphorus, including inorganic and organic compounds such as dissolved phosphate, particulate phosphorus (i.e. phosphorus bound to particles or suspended solids in the water) and organic phosphorus in organic material such as plant and animal matter. Total phosphorus in the river can come from various points and non-point sources derived from natural materials and anthropogenic activities. The natural sources of phosphorus can be the weathering of rocks and soils containing phosphate minerals, leaking to the river, from the organic matter decomposition of plants and animals releasing phosphorus into the river, and from the atmospheric deposition through rain and dust consisting of phosphorus. The anthropogenic sources of phosphorus are agricultural runoff containing phosphates from fertilizers and livestock manure discharged to the river, wastewater discharges, stormwater runoff in urban and suburban areas, and industrial discharges. In addition, the sources of TOTP are also from the instream, such as phosphorus released from dead algae and phosphorus attached to the suspended sediment. The excess of TOTP in the river water can cause algae blooms, decrease water quality, and impact the food webs.

In the Mekong River, TOTP ranges from below detection limit to 2.20 mg/L (0.09 mg/L, on average) since it is monitored. In tributaries, the temporal averages of TOTP are 0.07 mg/L, 0.07 mg/L, 0.09 mg/L, 0.14 mg/L, 0.15 mg/L and 0.17 mg/L, respectively, in Lao PDR's tributaries, Thailand's tributaries, 3S river system, Bassac River, Tonle Sap River and Viet Nam's Delta. In the Lower Mekong River, the target value of TOTP is 0.13 mg/L and is used for calculating the Water Quality Index for the Protection of Aquatic Life (WQI_{aq}, see Annex F). Hence, the concentration of TOTP exceeding 0.13 can cause a negative impact on the water quality of the river, which can lead to algae blooms, reduced oxygen levels, and harm to aquatic life. Although the average value of TOTP is below the target values for the WQI_{aq} in the Mekong River, the average temporal values indicated that the exceeded TOTP is occasionally observed in the upstream and middle stream, and more frequently recorded in the downstream (Figure 3.10). There were 10 stations that showed an increasing trend of TOTP, six stations that showed no trend, and only one station that indicated a decreasing trend of TOTP (VCD in Viet Nam). In the tributaries, Lao PDR and Thailand's tributaries were less frequently indicated by the exceedance TOTP (Figure 3.10b,c). However, all the stations in Lao PDR's tributaries showed an increasing trend of TOTP, while only TCR and TUB of Thailand's tributaries indicated an increasing trend, and the other stations showed no trend. In the Bassac and Tonle Sap Rivers, an increasing trend of TOTP was observed at all stations, and the annual average TOTP commonly exceeded the target value of 0.13 mg/L (Figure 3.10e,g). In the 3S river system, two stations recorded an increasing trend; three stations showed no trend; and one station showed a decreasing trend (Figure 3.10d).

Regarding Viet Nam's Delta, VTB and VTT showed a decreasing trend, and VTH showed an increasing trend (Figure 3.10f). Overall, in 2024, there were 31 of 48 stations of WQMN (65%), indicating an increasing trend of TOTP, especially in the tributaries. However, there were limited studies on the causes of increased TOTP in the Mekong River and its tributaries. Therefore, there should be more consideration of the sources and impact of increasing phosphorus concentration in the Mekong River and its tributaries. On this basis, appropriate solutions can be applied for reducing the input of phosphorus and mitigating its impacts on the water quality and the aquatic life. Some solutions can be identified for reducing the inputs of TOTP and TOTN, as follows:

- improving urban stormwater management, for example, applying green infrastructure such as green roofs and permeable pavement;
- controlling the wastewater discharge to the river, improving the sewer system, and developing the wastewater treatment plants;
- considering appropriate nature-based solutions, especially the buffer zones of wetlands.
- regularly dredging sediments to remove sources of TOP and TOTN; and
- implementing proper management of nutrient sources from agricultural activities.

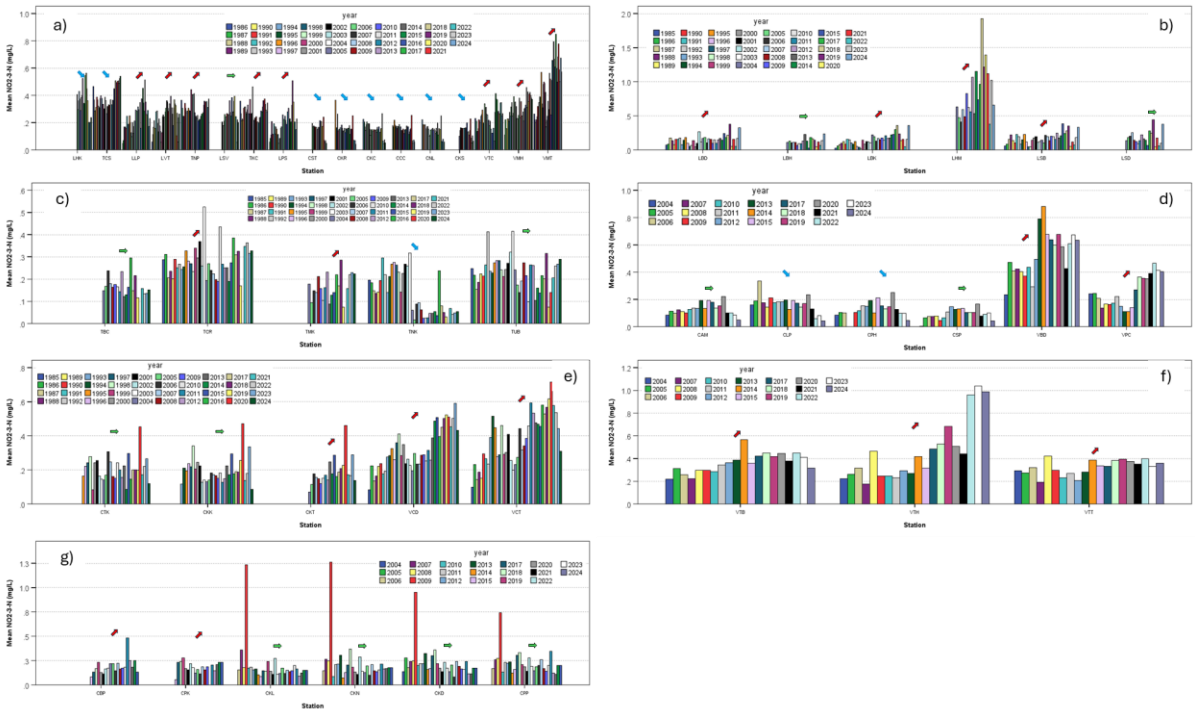


Figure 3.7. Temporal variation of mean annual $NO_{3\text{-}2}$-N concentrations of 48 water quality monitoring stations along (a) the Mekong River; (b) Lao PDR's tributaries; (c) Thailand's tributaries stations; (d) 3S's stations(e) Bassac River's stations; (f) Viet Nam'scanal stations; and (g) Tonle Sap's stations.

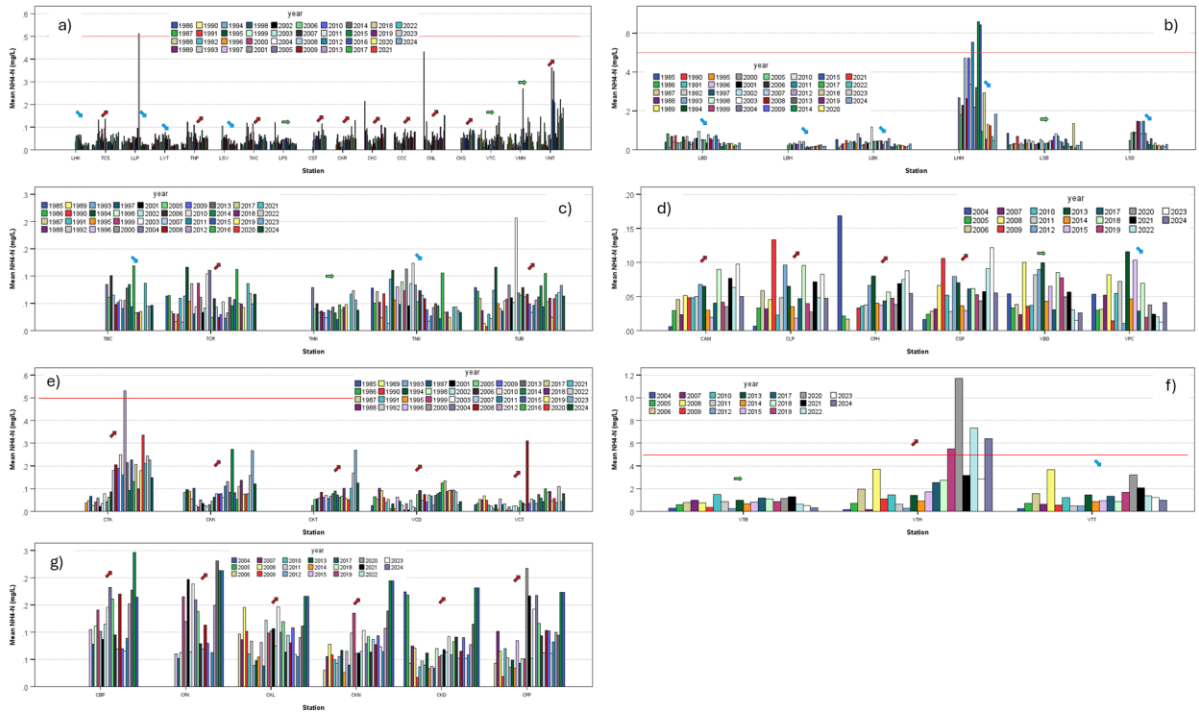


Figure 3.8. Temporal variation of mean annual NH_4-N concentrations of 48 water quality monitoring stations along (a) the Mekong River; (b) Lao PDR's tributaries; (c) Thailand's tributaries stations; (d) 3S's stations(e) Bassac River's stations; (f) Viet Nam's canal stations; and (g) Tonle Sap's stations.

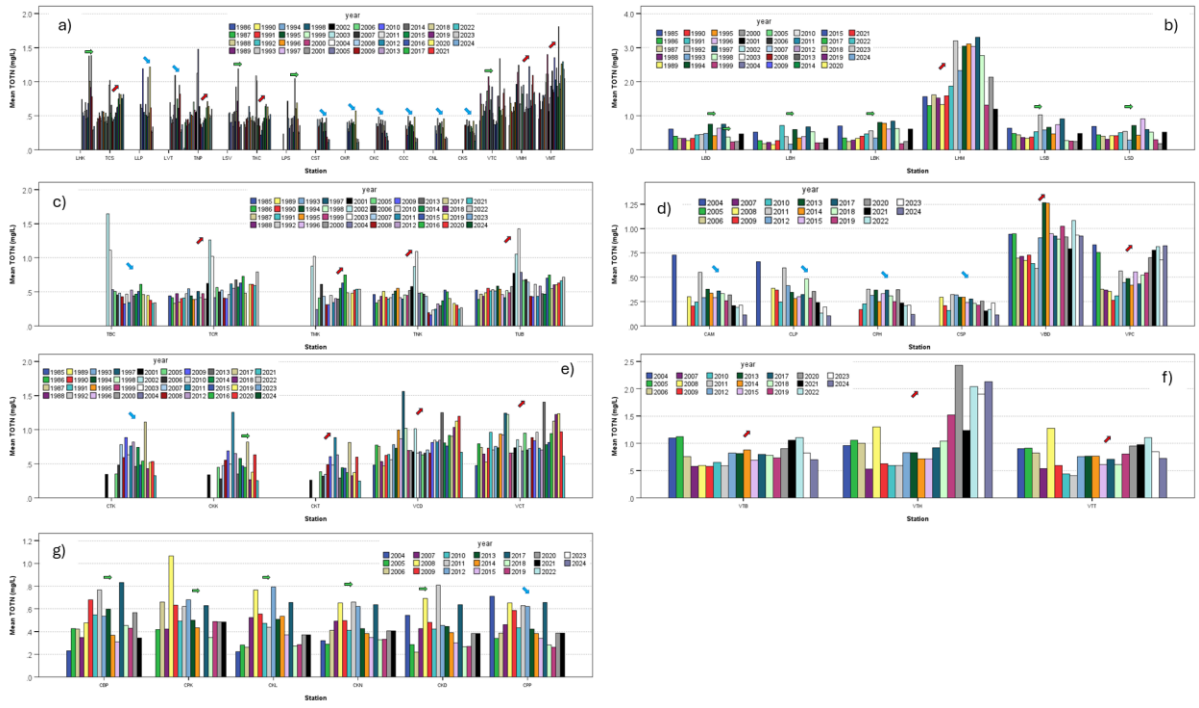


Figure 3.9. Temporal variation of mean annual TOTN concentrations of 48 water quality monitoring stations along (a) the Mekong River; (b) Lao PDR's tributaries; (c) Thailand's tributaries stations; (d) 3S's stations; (e) Bassac River's stations; (f) Viet Nam's canal stations; and (g) Tonle Sap's stations.

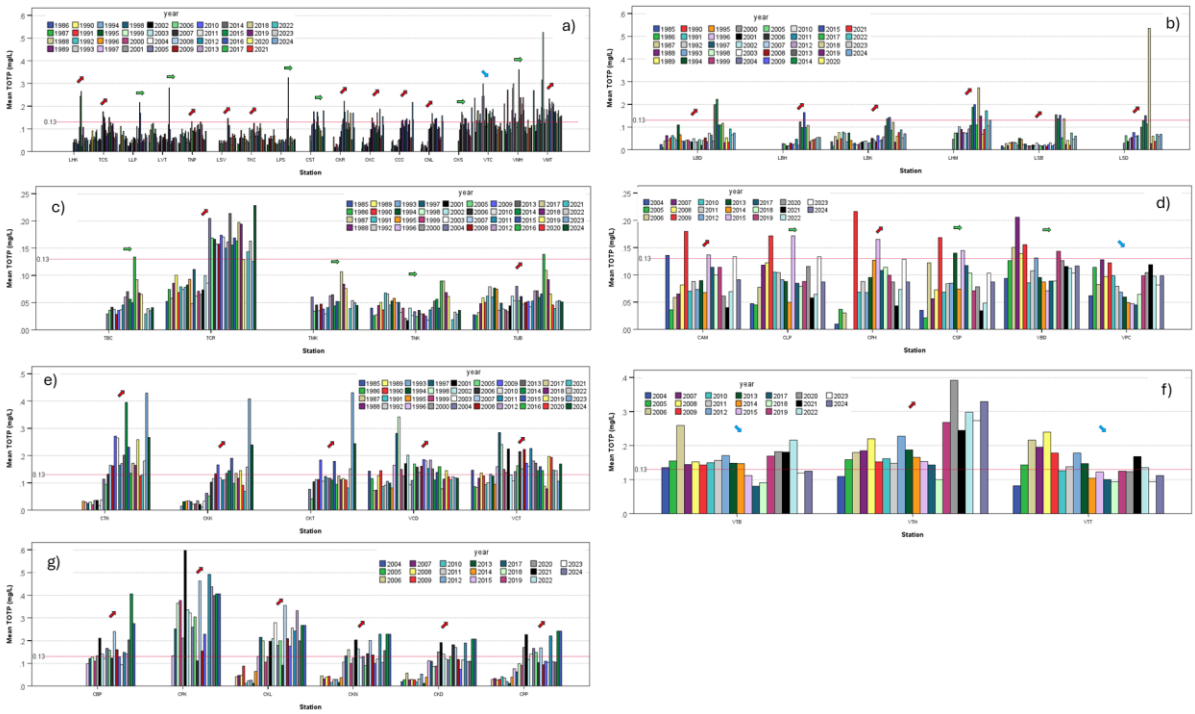


Figure 3.10. Temporal variation of mean annual TOTP concentrations of 48 water quality monitoring stations along (a) the Mekong River; (b) Lao PDR's tributaries; (c) Thailand's tributaries stations; (d) 3S's stations; (e) Bassac River's stations; (f) Viet Nam's canal stations; and (g) Tonle Sap's stations.

3.4 TRANSBOUNDARY WATER QUALITY

In the 2024 Water Quality report, three sets of transboundary water quality monitoring are considered part of this regional report, comprising six stations, including Pleicu (VPC) vs. Phum Phi (CPH), Kraorm Samnor (CKS) vs. Tan Chau (VTC) and Koh Thom (CKT) vs. Chau Doc (VCD). In 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 3.11.

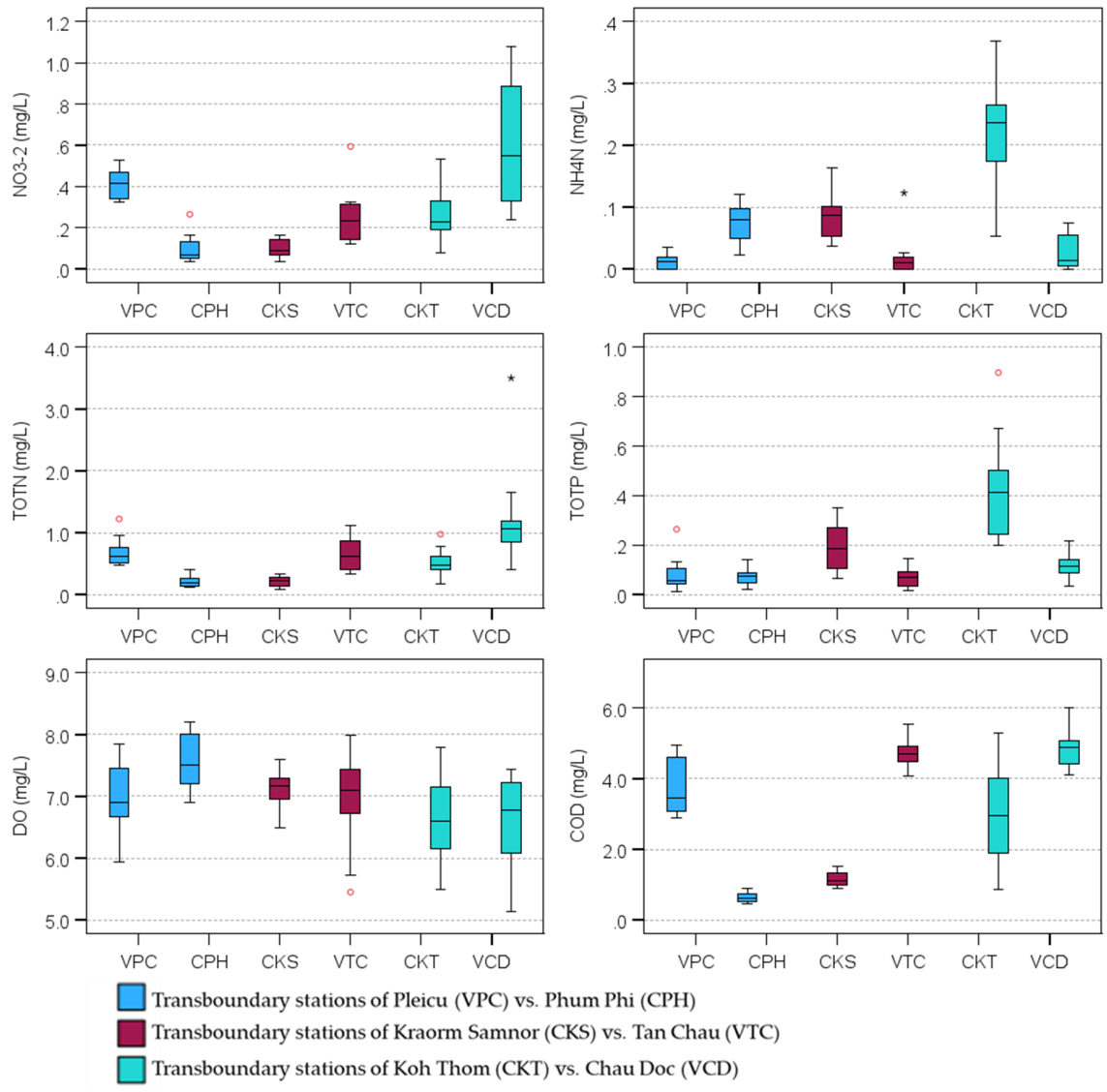


Figure 3.11. Comparisons of 2024 water quality data at the designated transboundary stations of WQMN

3.4.1 Pakse vs. Stung Treng 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 Highlands 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, 2024

Indicators	Stations	Mean (mg/L)	Std. deviation	p-value
NO_{3-2}	CPH	0.047	0.024	<0.001
	VPC	0.404	0.154	
NH_4N	CPH	0.055	0.026	0.415
	VPC	0.041	0.052	
TOTN	CPH	0.118	0.065	<0.001
	VPC	0.824	0.566	
TOTP	CPH	0.087	0.047	0.700
	VPC	0.098	0.088	
DO	CPH	7.715	0.400	<0.001
	VPC	6.648	0.518	
COD	CPH	0.603	0.161	<0.001
	VPC	3.314	0.480	

In 2024, statistically significant differences were found for NO_{3-2}-N, TOTN, DO and COD, with P-values less than 0.01. The average values of NO_{3-2}-N, TOTN and TOTP were higher in the upstream station (VPC) and lower in the downstream station (CPH) (Table 3.5). Therefore, the decreased trend observed for the concentrations of NO_{3-2}-N, TOTN and COD indicated that there was no potential for transboundary water quality issues.

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 an exploratory analysis 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 3.11.

Table 3.6 shows the significant differences between CKS and VTC stations in terms of NO_{3-2}, NH_4N, TOTN and COD. The data reveal that assessed parameters were degraded at VTC compared to those at CKS according to increased concentrations of NO_{3-2}, TOTN and COD from CKS to VTC. Specifically, the mean concentrations of NO_{3-2} and COD recorded at VTC were approximately 4 and 5 times higher than those at CKS, respectively. This suggests that there were 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 the 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, 2024

Indicators	Stations	Mean (mg/L)	Std. deviation	p-value
NO_{3-2}	CKS	0.066	0.031	<0.001
	VTC	0.267	0.134	
NH_4N	CKS	0.071	0.037	0.001
	VTC	0.039	0.034	
TOTN	CKS	0.374	0.491	0.030
	VTC	0.478	0.273	
TOTP	CKS	0.128	0.070	0.215
	VTC	0.091	0.039	
DO	CKS	6.971	0.253	0.075
	VTC	6.821	0.740	
COD	CKS	0.877	0.115	0.000
	VTC	4.823	0.044	

3.4.3 Koh Thom vs. Chau Doc

A similar analysis was carried out for Koh Thom (CKT) (on the Cambodian side of the river) and Chau Doc (VCD) (on the Vietnamese side of the river) water quality monitoring stations on the Bassac River to explore potential transboundary water quality issues. Figure 3.11 compares the concentrations of NO_{3-2}, NH_4H, TOTN, TOTP, DO and COD recorded at CKT and VCD monitoring stations in 2024.

Table 3.7 shows the statistically significant differences in all evaluated parameters except for DO. With the exception of DO, the mean values of NO_{3-2}, TOTN and COD recorded in VCD were higher than those at CKT. Specifically, the annual mean value of NO_{3-2}, TOTN and COD were 0.433 mg/L, 0.248 mg/L and 4.795 mg/L in VCD and, respectively, approximately 3.1, 2.7 and 3.3 times higher than those in CKT (0.138 mg/L, 0.278mg/L and 1.453 mg/L, respectively). The significant differences of NH_4-N and TOTP were related to higher values in CKT. As recommended for CKS and VTC potential transboundary water quality issues, a joint water quality assessment between Cambodia and Viet Nam should be carried out to determine the sources and causes of water quality degradation downstream.

Table 3.7. Statistical analyses of nutrient parameters monitored at CKT and VCD, 2024

Indicators	Stations	Mean (mg/L)	Std. deviation	p-value
NO_{3-2}	CKT	0.138	0.195	0.001
	VCD	0.433	0.169	
NH_4N	CKT	0.189	0.213	0.030
	VCD	0.042	0.051	
TOTN	CKT	0.248	0.076	<0.001
	VCD	0.676	0.237	
TOTP	CKT	0.242	0.052	<0.001

	VCD	0.119	0.122	
DO	CKT	6.789	0.218	0.339
	VCD	6.349	0.630	
COD	CKT	1.453	0.411	<0.001
	VCD	4.795	0.332	

3.5 WATER QUALITY INDICES

The 2024 water quality status of the Mekong River and its tributaries for the protection of human health, aquatic life and agricultural use (general and paddy rice irrigation) is 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, 2024

Station Abbr.	Station Names	River Names	WQI_{hh}	WQIal	WQI_{ag} (general irrigation)	WQI_{ag} (paddy irrigation)
LHK	Houa Khong	Mekong	A	A	A	A
TCS	Chiang Sean	Mekong	B	B	A	A
LLP	Luang Prabang	Mekong	A	A	A	A
LVT	Vientiane	Mekong	A	A	A	A
TNP	Nakhon Phanom	Mekong	B	B	A	A
LSV	Savannakhet	Mekong	B	A	A	A
TKC	Khong Chaim	Mekong	B	B	A	A
LPS	Pakse	Mekong	A	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
CKS	Kaorm Samnor	Mekong	A	B	A	A
VTC	Tan Chau	Mekong	B	A	A	A
VMH	My Thuan	Mekong	B	B	A	A
VMT	My Tho	Mekong	C	C	B	A
Lao PDR's Tributaries						
LBK	Ban Hatkham	Nam Ou	B	B	A	A
LBH	Ban Hai	Nam Ngum	A	A	A	A
LSD	Sedone bridge	Sedone	A	B	A	A
LSB	Se Bangfai	Se Bangfai	B	B	A	A
LBD	Ban Kengdone	Se Banghieng	B	B	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	A	A	A

Station Abbr.	Station Names	River Names	WQI_{hh}	WQIal	WQI_{ag} (general irrigation)	WQI_{ag} (paddy irrigation)
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		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	A	B	A	A
CPH	Phum Pi	Se San	A	A	A	A
CAM	Angdoung Meas	Se San	A	B	A	A
CLP	Lumphat	Sre Pok	A	A	A	A
CSP	Siempang	Se Kong	A	A	A	A
Viet Nam's Canal						
VTT	Tu Thuong	Tu Thoung	B	B	A	A
VTH	Thong Binh	Thong Binh	B	C	A	A
VTB	Tinh Bien	Tinh Bien	B	B	A	A
Bassac River						
CTK	Takhmao	Bassac	A	B	A	A
CKK	Koh Khel	Bassac	A	B	A	A
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 2024, the water quality of the Mekong and its tributaries was rated from “moderate” to “high” quality for the protection of aquatic life (Table 3.8). In the mainstream, six stations were rated as “high” quality, and 10 stations were “good” quality for the protection of aquatic life. At “good” water quality stations, NO_{3-2} and TOTP are the two parameters occasionally that exceeded the target values. The only station rated “moderate” was impacted by the saline water intrusion observed at My Tho in the dry season.

Along the tributaries of the Mekong River, the water quality at eight stations was rated as "high" for the protection of aquatic life, while 21 stations were rated as "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 NO_{3-2} of WQI_{al} (0.5 mg/L) and TOTP (0.13 mg/L).

Overall, 45 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 2024 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, 10 stations were rated as "excellent" and 6 stations as good" for the protection of human health (Table 3.8). At the eight "good" stations, COD was the indicator that did not meet the target value of the WQIhh (5 mg/L). The "moderate" quality station is mainly affected by the saline water intrusion in the dry season.

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, 58% of COD concentrations exceeded 5 mg/L (the target value of WQGH), while 25% of DO concentrations were lower than the target value used for WQI_{hh} calculation (Annex F, Table F3).

Overall, water quality at 46 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 2011 guidelines of the World Health Organization.

3.5.3 Water Quality Index for Agricultural Use

The level of impairment of water quality for agricultural use was assessed using the MRC Water Quality Indices for Agricultural Use. While two indices were adopted by the MRC to assess the level of impairment of water quality for general and paddy rice irrigation, all indices for agricultural use can be assessed against threshold values for EC (Annex F, Table F5).

In 2024, the EC at My Tho (VMT) showed "some restriction" rate. This indicates salinization affecting the water quality during the dry season in 2025. Water quality of the Mekong River and its tributaries were rated as "no restriction" for the general irrigation use at 47 stations (Table 3.8).

From 2010 to 2024, 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**). The only exceptions were in 2016, 2020, 2021 and 2024 at My Tho (VMT), which resulted from a prolonged seawater intrusion (**Annex D**), as 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 2024, 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 2024 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 2024 varied spatially from "good" to "excellent" for the protection of human health at 46 stations; one station was rated as "moderate". The "moderate" water quality at the VMT station was located in the mainstream of Viet Nam and at the LHM of Lao PDR's tributaries, where instream water quality continued to be periodically affected by elevated EC and COD levels, and reduced DO levels.
- With regard to the protection of aquatic life, the water quality of the Mekong and its tributaries was rated from "good" to "high" at the 45 stations of the WQMN, and three stations were rated "moderate".
- Similar to 2023, in 2024, elevated FC concentrations continued to be recorded at some mainstream and tributary stations, where human activities are intensive. However, the effect was local or not extend to the downstream stations.
- Saltwater intrusion was observed at VTM in the dry season, which was rated "some restriction" for both general and paddy irrigation. 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 activity 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}.
- Faecal pollution continued to impact the water quality at stations where human activities are intensive.
- Compared to 2023, in 2024, the water quality with respect to DO values was stable, with an improvement with respect to that in 2022.
- The trend analysis for nutrient parameters (NO_{3-2}, NH_4N, TOTN and TOTP) indicated that the trend variation occurred according to locations:
    - NO_{3-2} mostly showed an increasing trend in Lao PDR, Thailand and Viet Nam, while mostly showed a decreasing trend in Cambodia.

- The increasing trend is dominant in the LMB for NH_4 in the mainstream. The decreasing trend of NH_4 is observed at stations in Lao PDR, including LHK, LSV, LLP and LVT. Similar to the mainstream, an increasing trend is mostly observed in the tributaries. However, a decreasing or no trend is mainly shown in tributaries of Lao PDR and Cambodia.
- TOTN showed the dominance of a decreasing and no trend in the mainstream (12 out of 17 stations). An increasing trend of TOTN was observed at TCS, TNP, VMH and VMT. In the tributaries, the number of stations with decreasing or no trend is higher than those with an increasing trend (18 compared to 13).
- The increasing trend of TOTP is mostly shown at stations in both mainstream and tributaries.

In terms of potential transboundary water quality issues in 2024, the analyses of NO_{3-2}, TOTN, TOTP and COD suggest potential transboundary water quality issues between CKT and VCD stations, 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}, TOTN and COD concentrations recorded at VTC than at CKS. The differences in mean concentrations were found to be statistically significant.

4.2 RECOMMENDATIONS

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

- Conduct surveys and studies to clarify the causes of potential transboundary water quality issues at reported stations as soon as possible, with confirmed additional sampling locations by Cambodia and Viet Nam.
- 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, as part of the overall review of the implementation of the Procedures for Water Quality and its technical guidelines.
- Continue to strengthen the capacity of the MCs to monitor water quality associated with development, including the operation of automated high frequency water quality monitoring.
- Continue to advocate for and support the strengthening of cooperation among the MCs for water quality monitoring through a technical exchange of WQMN laboratory staffs.
- Improve solid waste and wastewater management in order to mitigate the impacts on human health at locations that observed faecal pollution.

Investigate the causes for the increasing trend in nutrient parameters in the LMB to provide suitable mitigation measures.

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ANNEX A – 2024 WATER QUALITY STATUS OF THE MEKONG RIVER AS MONITORED AT 17 MAINSTREAM STATIONS

Stations[2]	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	7.71	198.80	42.20	0.12	0.14	0.28	0.29	7.25	1.55	1.25
	Mean	7.17	68.43	28.41	0.06	0.08	0.16	0.14	7.01	0.91	0.72
	Median	7.14	47.55	28.04	0.05	0.08	0.16	0.09	7.05	0.88	0.60
	Minimum	6.62	6.30	15.40	0.03	0.03	0.07	0.05	6.50	0.60	0.40
	Std. deviation	0.35	68.90	10.93	0.03	0.04	0.07	0.09	0.21	0.28	0.29
CKC	Maximum	7.65	176.90	42.67	0.08	0.46	0.22	0.23	7.70	0.89	0.95
	Mean	7.12	69.04	28.12	0.05	0.10	0.14	0.12	7.19	0.73	0.57
	Median	7.07	42.70	26.73	0.05	0.06	0.14	0.09	7.28	0.74	0.53
	Minimum	6.70	7.50	15.78	0.03	0.03	0.07	0.05	6.50	0.50	0.35
	Std. deviation	0.29	66.23	10.75	0.02	0.12	0.05	0.07	0.35	0.12	0.18

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

Stations[2]	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
CKR	Maximum	7.65	196.50	42.45	0.07	0.08	0.18	0.21	8.10	0.75	
	Mean	7.07	70.36	27.77	0.04	0.05	0.12	0.11	7.52	0.63	
	Median	6.93	41.10	26.61	0.04	0.05	0.11	0.08	7.58	0.63	
	Minimum	6.65	6.90	15.53	0.03	0.03	0.06	0.05	6.50	0.50	
	Std. deviation	0.33	68.76	10.98	0.01	0.02	0.04	0.06	0.46	0.09	
CKS	Maximum	7.75	165.00	42.60	0.13	0.15	1.73	0.22	7.25	1.05	
	Mean	7.17	66.23	28.33	0.07	0.07	0.37	0.13	6.97	0.88	
	Median	7.09	43.25	27.99	0.05	0.06	0.21	0.08	7.02	0.88	
	Minimum	6.80	7.80	16.10	0.03	0.03	0.10	0.06	6.55	0.75	
	Std. deviation	0.29	62.67	10.52	0.03	0.04	0.49	0.07	0.25	0.11	
CNL	Maximum	7.77	170.50	42.70	0.10	0.96	0.26	0.24	7.40	1.24	1.30
	Mean	7.17	71.43	28.36	0.06	0.15	0.17	0.13	6.95	0.88	0.66
	Median	7.04	49.10	28.18	0.05	0.07	0.17	0.08	6.98	0.89	0.68
	Minimum	6.80	8.20	16.08	0.03	0.04	0.08	0.06	6.30	0.50	0.04
	Std. deviation	0.30	67.44	10.55	0.02	0.26	0.07	0.08	0.31	0.21	0.37

Stations[2]	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
CST	Maximum	7.45	198.30	48.40	0.08	0.08	0.22	0.22	7.80	0.90	
	Mean	7.08	64.58	30.16	0.05	0.06	0.15	0.11	7.19	0.65	
	Median	7.15	31.70	28.92	0.05	0.06	0.15	0.09	7.15	0.67	
	Minimum	6.64	7.60	15.80	0.03	0.03	0.08	0.05	6.65	0.07	
	Std. deviation	0.23	68.11	11.38	0.02	0.02	0.05	0.06	0.38	0.21	
LHK	Maximum	8.60	202.00	37.00	0.38	0.07	0.48	0.09	7.90	4.89	
	Mean	7.69	60.81	30.88	0.24	0.03	0.34	0.05	7.52	2.50	
	Median	7.76	28.42	32.70	0.24	0.03	0.35	0.04	7.55	2.55	
	Minimum	7.09	1.80	18.70	0.07	0.01	0.15	0.01	7.02	0.24	
	Std. deviation	0.43	67.61	5.74	0.08	0.02	0.08	0.03	0.33	1.21	
LLP	Maximum	7.62	545.00	35.90	0.37	0.04	0.51	0.13	7.23	4.81	
	Mean	7.33	143.14	27.50	0.23	0.02	0.34	0.06	6.81	3.22	
	Median	7.33	83.30	28.25	0.22	0.02	0.33	0.05	6.93	3.05	
	Minimum	7.09	8.00	19.10	0.15	0.01	0.25	0.01	6.00	1.83	
	Std. deviation	0.20	184.93	4.56	0.06	0.01	0.07	0.05	0.36	0.93	

Stations[2]	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
LPS	Maximum	7.96	531.00	51.80	0.40	0.09	0.54	0.17	7.30	3.12	
	Mean	7.26	95.11	27.30	0.23	0.03	0.36	0.05	6.66	2.45	
	Median	7.23	14.15	25.35	0.20	0.02	0.31	0.06	6.68	2.50	
	Minimum	6.66	5.33	14.20	0.02	0.01	0.21	0.01	6.18	1.78	
	Std. deviation	0.36	149.57	11.84	0.11	0.02	0.13	0.05	0.33	0.45	
LSV	Maximum	6.95	674.00	45.90	0.29	0.07	0.56	0.15	7.55	4.67	
	Mean	6.29	96.92	27.92	0.20	0.03	0.37	0.06	6.94	2.85	
	Median	6.23	23.32	29.15	0.20	0.03	0.35	0.06	7.00	2.96	
	Minimum	5.56	3.20	10.19	0.11	0.01	0.24	0.01	6.18	0.24	
	Std. deviation	0.40	191.46	12.48	0.05	0.02	0.09	0.04	0.32	1.20	
LVT	Maximum	8.18	383.00	29.40	0.38	0.04	0.47	0.10	8.73	4.15	2.25
	Mean	7.57	74.69	24.31	0.27	0.02	0.37	0.06	7.48	3.04	1.48
	Median	7.55	22.99	26.05	0.26	0.02	0.39	0.06	7.47	3.21	1.41
	Minimum	7.00	6.00	16.96	0.17	0.01	0.27	0.01	6.99	0.99	0.76
	Std. deviation	0.34	116.73	4.63	0.06	0.01	0.06	0.03	0.49	0.94	0.48

Stations[2]	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
TCS	Maximum	8.44	611.20	34.25	0.69	0.18	1.42	0.21	10.13	9.00	1.90
	Mean	7.88	153.39	28.00	0.54	0.08	0.82	0.08	8.57	3.45	1.17
	Median	7.82	116.60	28.47	0.51	0.08	0.71	0.08	8.63	3.28	1.30
	Minimum	7.41	6.20	16.46	0.43	0.00	0.59	0.01	7.35	0.87	0.20
	Std. deviation	0.34	191.97	5.59	0.09	0.06	0.25	0.06	0.81	2.58	0.56
TKC	Maximum	8.40	641.00	49.85	0.63	0.10	0.97	0.25	9.08	9.21	1.50
	Mean	7.92	121.35	31.11	0.35	0.04	0.52	0.08	7.71	2.90	0.82
	Median	7.88	25.70	30.24	0.38	0.03	0.52	0.05	7.66	1.61	0.78
	Minimum	7.65	3.60	16.46	0.13	0.00	0.17	0.01	6.70	0.21	0.22
	Std. deviation	0.23	197.11	10.81	0.18	0.04	0.25	0.08	0.69	2.69	0.41
TNP	Maximum	8.25	641.80	30.00	0.86	0.15	1.31	0.28	9.06	7.99	2.29
	Mean	7.83	146.72	20.38	0.38	0.05	0.60	0.09	6.95	3.50	1.29
	Median	7.78	38.20	21.06	0.39	0.02	0.52	0.06	6.83	1.98	1.30
	Minimum	7.50	7.20	12.62	0.10	0.00	0.15	0.02	5.77	1.19	0.22
	Std. deviation	0.25	200.86	4.61	0.24	0.05	0.33	0.08	1.00	2.56	0.54

Stations[2]	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
VMH	Maximum	7.65	85.00	43.00	0.50	0.03	1.27	0.27	7.26	5.27	2.72
	Mean	7.33	25.08	24.35	0.37	0.01	0.67	0.12	6.86	4.92	2.33
	Median	7.32	18.50	20.85	0.37	0.01	0.66	0.09	6.85	5.00	2.32
	Minimum	7.11	4.00	13.30	0.16	0.00	0.30	0.03	6.49	4.21	1.90
	Std. deviation	0.16	25.31	10.56	0.11	0.01	0.29	0.07	0.23	0.30	0.23
VMT	Maximum	7.49	652.00	525.00	1.12	1.33	2.51	0.38	7.15	6.88	4.18
	Mean	6.89	92.75	118.28	0.57	0.19	1.05	0.16	6.28	4.88	2.70
	Median	7.07	38.00	29.25	0.53	0.02	0.72	0.16	6.20	4.75	2.48
	Minimum	5.96	22.00	17.20	0.02	0.00	0.28	0.00	5.65	4.20	2.21
	Std. deviation	0.48	177.04	174.96	0.36	0.38	0.74	0.10	0.46	0.77	0.55
VTC	Maximum	7.79	65.00	42.30	0.46	0.16	0.92	0.27	7.70	5.16	2.63
	Mean	7.32	26.33	24.68	0.27	0.04	0.48	0.09	6.82	4.82	2.30
	Median	7.30	11.00	20.90	0.27	0.03	0.54	0.08	6.65	4.89	2.29
	Minimum	6.92	5.00	13.30	0.04	0.00	0.08	0.02	6.12	4.40	1.90
	Std. deviation	0.25	25.13	10.29	0.12	0.04	0.24	0.07	0.55	0.23	0.20

Stations[2]	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
Total	Maximum	8.60	674.00	525.00	1.12	1.33	2.51	0.38	10.13	9.21	4.18
	Mean	7.30	84.74	32.72	0.23	0.06	0.41	0.10	7.14	2.54	1.41
	Median	7.28	30.00	26.99	0.18	0.03	0.31	0.07	7.08	2.00	1.25
	Minimum	5.56	1.80	10.19	0.02	0.00	0.06	0.00	5.65	0.07	0.04
	Std. deviation	0.50	129.57	47.07	0.21	0.12	0.36	0.07	0.68	1.91	0.84

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

No.	Station Names	Countries	Class														
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	Houa Khong	Lao PDR	A	A	B	B	B	B	B	B	B	A	A	A	A	A	A
2	Chiang Sean	Thailand	B	A	B	B	A	B	B	B	B	A	B	B	B	B	B
3	Luang Prabang	Lao PDR	B	A	A	B	B	B	A	B	A	A	A	A	A	A	A
4	Vientiane	Lao PDR	A	A	A	B	B	A	A	A	A	A	A	A	A	A	A
5	Nakhon Phanom	Thailand	B	A	B	B	A	A	B	B	B	A	A	A	A	A	B
6	Savannakhet	Lao PDR	A	A	A	B	B	B	A	A	B	A	A	A	A	A	A
7	Khong Chaim	Thailand	A	A	A	B	A	A	A	B	A	A	A	A	A	A	B
8	Pakse	Lao PDR	A	A	A	B	B	B	A	A	B	A	A	A	A	A	A
9	Stung Treng	Cambodia	B	B	B	B	B	B	B	A	A	A	A	A	A	B	B
10	Kratie	Cambodia	B	B	B	B	B	B	A	B	B	B	A	A	A	B	B
11	Kampong Cham	Cambodia	B	B	B	B	A	B	A	A	B	B	A	A	A	B	B
12	Chrouy Changvar	Cambodia	B	B	B	B	B	B	A	A	B	B	A	A	A	B	B
13	Neak Loung	Cambodia	B	B	B	B	B	B	A	A	B	A	A	A	A	B	B
14	Kaorm Samnor	Cambodia	B	B	B	B	B	B	A	A	B	A	A	A	A	B	B
15	Tan Chau	Viet Nam	B	B	B	B	B	B	B	A	B	B	B	B	B	A	A
16	My Thuan	Viet Nam	B	B	B	B	B	B	B	B	B	B	B	B	B	A	B
17	My Tho	Viet Nam	C	C	B	C	C	C	D	C	B	C	C	C	C	B	C
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	A	B	B	B
20	Koh Thom	Cambodia	B	B	B	B	A	B	B	B	B	A	B	A	B	B	B
21	Chau Doc	Viet Nam	B	B	B	B	B	B	B	B	C	C	C	B	B	B	B
22	Can Tho	Viet Nam	C	C	C	C	B	B	B	B	B	C	C	C	B	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													
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	Houa Khong	Lao PDR	B	A	B	B	C	A	A	A	B	A	A	A	B	B	A
2	Chiang Sean	Thailand	B	A	B	B	B	B	B	B	B	A	A	B	B	B	B
3	Luang Prabang	Lao PDR	B	A	B	A	B	B	B	A	B	A	A	A	A	A	A
4	Vientiane	Lao PDR	B	A	B	B	B	B	B	A	A	A	B	A	B	A	A
5	Nakhon Phanom	Thailand	B	B	B	B	B	B	B	B	B	B	A	B	B	B	B
6	Savannakhet	Lao PDR	A	A	B	B	C	B	B	A	A	A	A	A	B	A	B
7	Khong Chaim	Thailand	B	A	B	B	B	B	B	B	B	A	B	B	A	A	B
8	Pakse	Lao PDR	A	A	A	B	A	B	B	A	A	A	B	A	A	B	A
9	Stung Treng	Cambodia	A	A	A	A	A	A	A	A	A	A	B	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	B	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	B	A	A	A	A	A	A	A	A	A
14	Kaorm Samnor	Cambodia	A	A	B	A	A	B	A	A	A	A	A	A	A	A	A
15	Tan Chau	Viet Nam	B	B	A	A	A	A	A	A	B	B	A	B	B	B	B
16	My Thuan	Viet Nam	C	A	A	B	A	A	A	B	B	A	B	B	B	B	B
17	My Tho	Viet Nam	C	B	B	B	B	A	B	B	B	A	B	C	B	B	C
18	Takhmao	Cambodia	A	A	A	B	C	A	B	A	B	B	B	B	B	B	B
19	Koh Khel	Cambodia	B	A	B	B	A	B	A	A	A	A	A	A	A	A	A
20	Koh Thom	Cambodia	A	A	B	B	A	A	A	A	A	A	A	A	A	A	A
21	Chau Doc	Viet Nam	C	B	B	A	A	A	A	B	B	B	A	B	B	B	B
22	Can Tho	Viet Nam	C	B	A	A	A	A	A	A	B	A	A	B	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														
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
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	B	A	A	A	C	B	A	A	B
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 NUTRIENT PARAMETERS IN THE MEKONG AND TRIBUTARIES BASED ON THE MONTHLY DATA, 1985–2024

	Stations	NO3-2	P-value	NH4-N	P-value	TOTN	P-value	TOTP	P-value
Mainstream	LHK	D	0.001	D	<0.001	No	0.092	I	0.046
	TCS	D	<0.001	I	<0.001	I	<0.001	I	<0.001
	LLP	I	<0.001	D	0.003	D	0.001	No	0.12
	LVT	I	<0.001	D	<0.001	D	0.013	No	0.35
	TNP	I	0.003	I	<0.001	I	<0.001	I	<0.001
	LSV	No	0.422	D	<0.001	No	0.488	I	<0.001
	TKC	I	0.011	I	0.011	I	0.003	I	0.002
	LPS	I	<0.001	No	0.095	No	0.136	No	0.163
	CST	D	<0.001	I	0.001	D	<0.001	No	0.171
	CKR	D	<0.001	I	<0.001	D	<0.001	I	<0.001
	CKC	D	<0.001	I	<0.001	D	<0.001	I	<0.001
	CCC	D	<0.001	I	<0.001	D	<0.001	I	<0.001
	CNL	D	<0.001	I	<0.001	D	<0.001	I	<0.001
	CKS	D	0.02	I	<0.001	D	<0.001	No	0.475
	VTC	I	<0.001	No	0.234	No	0.453	D	0.001
	VMH	I	<0.001	No	0.115	I	<0.001	No	0.733
	VMT	I	<0.001	I	<0.001	I	<0.001	I	0.005
Lao PDR's tributaries	LBD	I	<0.001	D	0.003	No	0.43	I	<0.001
	LBH	No	0.148	D	<0.001	No	0.376	I	<0.001
	LBK	I	<0.001	D	<0.001	No	0.953	I	<0.001
	LHM	I	0.005	D	<0.001	I	0.043	I	0.016
	LSB	I	<0.001	No	0.49	No	0.072	I	<0.001
	LSD	No	0.936	D	<0.001	No	0.218	No	0.305
Thailand's tributaries	TBC	No	0.204	D	<0.001	D	<0.001	No	0.057
	TCR	I	0.048	I	0.002	I	<0.001	I	<0.001
	TMK	I	0.05	No	0.43	I	<0.001	No	0.091
	TNK	D	<0.001	D	<0.001	I	<0.001	No	0.729
	TUB	No	0.056	I	0.001	I	<0.001	I	<0.001
3S river system	CAM	No	0.468	I	<0.001	D	<0.001	I	0.009
	CLP	D	<0.001	I	0.005	D	<0.001	No	0.48
	CPH	D	0.022	I	0.001	D	<0.001	I	0.024
	CSP	No	0.456	I	<0.001	D	<0.001	No	0.281
	VBD	I	<0.001	No	0.332	I	<0.001	No	0.357
	VPC	I	<0.001	D	0.018	I	<0.001	D	0.039
Tonle Sap river system	CBP	I	<0.001	I	<0.001	No	0.587	I	<0.001
	CKD	No	0.089	I	<0.001	No	0.565	I	<0.001
	CKL	No	0.572	I	<0.001	No	0.099	I	<0.001
	CKN	No	0.85	I	<0.001	No	0.609	I	<0.001
	CPK	I	0.004	I	<0.001	No	0.265	I	<0.001

	Stations	NO3-2	P-value	NH4-N	P-value	TOTN	P-value	TOTP	P-value
Bassac river system	CPP	No	0.84	I	<0.001	D	0.047	I	<0.001
	CKK	No	0.488	I	<0.001	D	0.007	I	<0.001
	CKT	I	<0.001	I	<0.001	No	0.222	I	<0.001
	CTK	No	0.566	I	<0.001	I	0.044	I	<0.001
	VCD	I	<0.001	I	<0.001	I	<0.001	I	<0.001
	VCT	I	<0.001	I	0.022	I	<0.001	I	<0.001
Viet Nam's Delta Canal	VTB	I	<0.001	No	0.313	I	0.031	D	0.011
	VTH	I	<0.001	I	<0.001	I	<0.001	I	<0.001
	VTT	I	<0.001	D	0.001	I	0.002	D	0.008

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

APPENDIX F – ASSESSMENT OF WATER QUALITY STATUS

1. Descriptive statistical analysis

The overall status of the Mekong water quality in 2024 was examined by applying descriptive statistics such as annual maximum, mean and minimum to summarize data series of key water quality parameters collected in 2024 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 (Fisher & Marshall, 2009; Lee & Bang 2020). These values were compared to the water quality thresholds of the MRC TGWQ Guidelines for the Protection of Human Health (Chapter 1) and for the Protection of Aquatic Life (Chapter 2TGWQ) 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 Water Quality Indices (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 Water Quality Indices. In addition, the proportions of data points that exceeded or violated water quality thresholds were also determined to quantify the extent or scale of water quality issues.

As illustrated in Figure 2.2, the assessment results of water quality status are then used as one of the key data to support the statistical analyses for determining spatiotemporal changes and transboundary water quality issues.

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 Water Quality Indices. In 2013, the MRC MCs adopted three indices taking into account the requirements of the PWQ and its TGWQ (Section 1.2.2). These indices are:

- 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.

a. The 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 1**. It was developed as an open-ended index, which would allow more parameters to be added once data become available (Campbell, 2014). In this annual water quality report, only six parameters are included, which, together with their target values, are listed in Table F1. The classification system for the WQI_{al}, is summarized in Table F2.

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

Where,

"p_i" is the number of the points scored on sample day i. If each parameter listed in Table F1 meets its respective target value in:

- Table F1, 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 F1. 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
$NO_{3\text{-}2}$ (mg/L)	0.5
TOTP (mg/L)	0.13

Table F2. Rating system 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

b. The 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 on the Implementation of the Procedures for Water Quality, the MRC MCs agreed to include HH in the analysis of water quality of the Mekong River. To assist in communicating water quality information on 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**, which is based on the Canadian Water Quality Index (CCME, 2001; Khan, Khan & Hall, 2005). It should be noted that, since the monitoring of direct impact parameters has not commenced, MCs have agreed to only adopt 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 F3. The classification system for the WQI_{hh} Index is summarized in Table F4.

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

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

$$F_1 = \left(\frac{\#\ of\ failed\ parameters}{Total\ \#\ of\ parameters} \right) \quad \text{Equation 3.}$$

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

$$F_2 = \left(\frac{\#\ of\ failed\ tests}{Total\ \#\ of\ tests} \right) \quad \text{Equation 4.}$$

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

$$F_3 = \left(\frac{nse}{0.01nse + 0.01} \right) \quad \text{Equation 5.}$$

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

$$nse = \left(\frac{\sum excursion}{Total\ \#\ of\ tests} \right) \quad \text{Equation 6.}$$

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

$$excursion = \left(\frac{failed\ test\ value}{guideline\ value} \right) - 1 \quad \text{Equation 7.}$$

Table F3. Parameters used for calculating the rating score of the Water Quality Index for the Protection of Human Health and their target values

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

Note: *Due to the required holding time for BOD, MCs 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 F4. 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 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

c. The Water Quality Index for Agricultural Use

Another index adopted by the MRC MCs as a means for communicating water quality monitoring information to the public is the Water Quality Index for Agricultural Use, focusing on water quality for general and paddy rice irrigation. The indices for general and paddy rice irrigation are outlined in Table F5.

Table F5. Electrical conductivity guidelines and degrees of consequence for Water Quality Index for Agricultural Use – general and paddy rice irrigation

Irrigation raw water	Unit	Degree of consequence*		
		None (A)	Some (B)	Severe (C)
Electrical conductivity				
General irrigation	mS/m	<70	70–300	>300
Paddy rice	mS/m	<200	200–480	>480

Note: None = 100% yield; Some = 50-90% yield; Severe = <50% yield.

3. Assessment of spatial variations

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

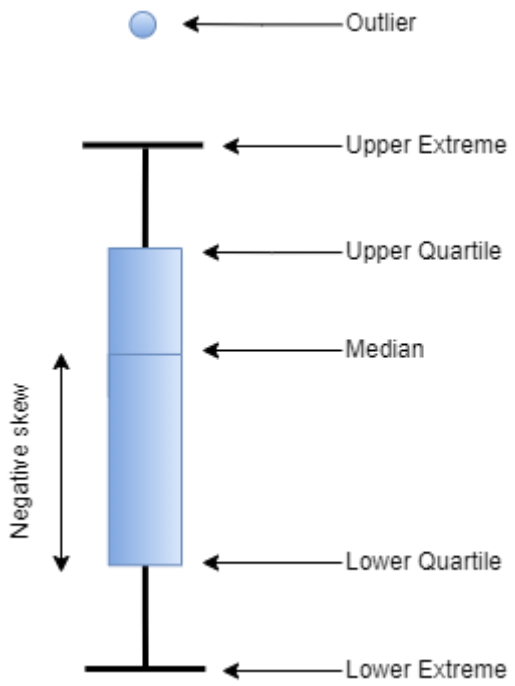


Figure 1. Information visualized by box-and-whisker plot

A box-and-whisker plot (Dutoit, Steyn & Stumpf, 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 distribute 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, including the information on the minimum, maximum and median, and the first and third quartile of the dataset (Larsen, 1985). As such, the box-and-whisker plot is an ideal graphical visualization for comparing data distribution of different dataset (e.g. water quality data from different stations or time step) due to its 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 2024 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 & Wilson, 2017). This is because while the box-and-whisker plot may visually indicate spatial water quality variations among the stations monitored in 2024, 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 & Wilson, 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 8.

$$H_0: \mu_1 = \mu_2 = \mu_3 = \cdots = \mu_n \qquad \text{Equation 8.}$$

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 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 & luliano, 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]:[$NO_{3\text{-}2}$]; [pH:[COD]; or [pH]:[TOTP], etc.)[3] 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:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \qquad \text{Equation 9.}$$

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).

4. Assessment of temporal variations

The 2024 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 mainstream. 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 1985–2024 period for many stations. Similar to the assessment of spatial variations, a combination of graphical visualizations and statistical analyses was

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

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, Verbyla & Oliveira , 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:

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 10 to 12 (Hirsch, Slack & Smith, 1982).

$$Z_{sk} = \frac{S'-1}{\sqrt{VAR(S')}} \quad if\ S' > 0 \qquad \text{Equation 10}$$

$$Z_{sk} = 0 \quad if\ S' = 0 \qquad \text{Equation 11}$$

$$Z_{sk} = \frac{S'+1}{\sqrt{VAR(S')}} \quad if\ S' < 0 \qquad \text{Equation 12}$$

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 provides 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.

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 LMB.
2. **Lao PDR/Myanmar** — No water quality station exists in this part of the river since it is remote and sparsely populated.
3. **Thailand/Lao PDR** — A number of monitoring stations exist along this stretch of the Mekong River, including those located in the vicinity of urban areas such as Vientiane (LVT), Nakhon Phanom (TNP) and Savannakhet (LSV). However, none of the` stations can be referred to as transboundary stations since they receive run-off from both countries, and water is normally sampled in the middle of the river.
4. **Lao PDR/Cambodia** — While not located directly at the border of the two countries, 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 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 2024 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 he box-and-whisker plot.

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 13), can be rejected. Should the t-test return statistically significant results at the 0.05 level, alternative hypothesis (H_A) would be accepted (Equation 14).

$$H_0: \mu_1 = \mu_2 \qquad \text{Equation 13}$$

$$H_A = \mu_1 \neq \mu_2 \qquad \text{Equation 14}$$

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 (IBM Corp., 2021).

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.

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 laboratory 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 the 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 the recommended holding times;
- conduct routine maintenance and calibration of all measurement equipment;

- conduct data analysis using a control chart and reliability score testing using the ion balance test; andarchive raw data and any important information relating to the results of the analysis in order to trace all data and to reconfirm the results.

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