Mekong River Commission
For Sustainable Development

2018 LOWER MEKONG WATER QUALITY MONITORING REPORT

October 2021

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

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Title: 2018 Lower Mekong water quality report

DOI: 10.52107/mrc.qx5ynz

Keywords: water quality/human health/Procedures for Water Quality/Lower Mekong River Basin/Mekong River Commission/Transboundary River/Spatiotemporal trends

For bibliographic purposes, this volume may be cited as:
Mekong River Commission. (2021). *2018 Lower Mekong water quality report*. Vientiane: MRC Secretariat. https://doi.org/10.52107/mrc.qx5ynz

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Citation

Mekong River Commission (2021). *2018 Lower Mekong water quality monitoring report*. Vientiane: MRC Secretariat. https://doi.org/10.52107/mrc.qx5ynz

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Abbreviations and acronyms

BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
CODMN	Chemical oxygen demand analysed using the permanganate oxidation Method
DO	Dissolved oxygen
EC	Electrical conductivity
EHM	Ecological Health Monitoring
ED	Environmental Management Division
HH	Human Health
ISO	International Organization for Standardization
LMB	Lower Mekong Basin
MC	Member Country
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NH_4N	Ammonium
NMC	National Mekong Committee
NMCS	National Mekong Committee Secretariat
NO_{32}	Nitrate-nitrile
PDIES	Procedures for Data and Information Exchange and Sharing
PWQ	Procedures for Water Quality
QA/QC	Quality Assurance/Quality Control
Sida	Swedish International Development Agency
TGWQ	Technical Guidelines for the Implementation of the Procedures for Water Quality
TOTN	Total nitrogen
TOTP	Total phosphorus
TSS	Total suspended solids
USEPA	United States Environmental Protection Agency
WQGA	MRC Water Quality Guidelines for the Protection of Aquatic Life
WQGH	MRC Water Quality Guidelines for the Protection of Human Health
WQI	Water Quality Index
WQI_{ag}	Water Quality Index for Agricultural Use
WQI_{al}	Water Quality Index for the Protection of Aquatic Life
WQI_{hh}	Water Quality Index for the Protection of Human Health
WQMN	Water Quality Monitoring Network

Executive summary

The Water Quality Monitoring Network (WQMN), which was established in 1985, has provided a continuous record of water quality in the Mekong River and its tributaries. The routine water quality monitoring under the WQMN is one of the key environmental monitoring activities at MRC, supporting the implementation of the Procedures for Water Quality (PWQ). The actual monitoring of water quality is being implemented by the designated laboratories of the Member Countries (MCs).

In 2018, the Mekong River Commission (MRC), with the assistance from MCs including Cambodia, Lao PDR, Thailand, and Viet Nam, conducted a routine monitoring of water quality in the Mekong River and its tributaries at 48 stations, of which 17 in the mainstream of the Mekong River and 31 in tributaries, of which five in the Bassac River. In 2018, in all stations, 18 parameters were measured, of which 12 are routine water quality parameters that are required to be measured for each sample month. The other six, major anions and major cations, were required to be analysed for each sample taken between April and October.

The results of the monitoring showed that the water quality in the Mekong and Bassac Rivers was still of good quality with the slight improvement compared with 2016. There was only a small number of measurements of chemical oxygen demand (COD) and dissolved oxygen (DO) that violated the MRC Water Quality Guidelines for the Protection of Human Health (WQGH) and the MRC Water Quality Guidelines for the Protection of Aquatic Life (WQGA). Most exceedances were recorded in the Delta. Of a slight concern was the DO level at Chau Doc, which violated the WQGH for all sampling occasions causing water quality for the protection of human health to be downgraded from 'good' in 2017 to 'moderate' in 2018. Using the Pearson's correlation analysis, the reduction in DO appear to be caused by the elevated levels in COD and NO_{32}. Despite the potential impairment to human health, the quality was still good for the protection of aquatic life.

When compared to 2017 data, water quality of the Mekong River did not change significantly in 2018. However, historical comparisons (1985 to 2018) appear to suggest that water quality had changed significantly for many parameters including total suspended solids (TSS), which saw a reduction of yearly mean concentration from 388 mg/L in 1985 to 84.9 mg/L in 2018. Concentrations of $NO_{2\text{-}3}$, NH_4, COD and DO also changed during the same period, with mean annual DO levels reduced from 7 mg/L in 1985 to 6.6 mg/L in 2018 while mean annual COD levels increased from 1.6 to 2.47 mg/L during the same period.

The assessment of the Water Quality Index for the Protection of Aquatic Life revealed that water quality in the Mekong and Bassac Rivers was still of good quality for the protection of aquatic life, with all stations rated as either 'good' or 'excellent'. Similarly, the Water Quality Index for the Protection of Human Health also reveals water quality to be of good quality for the protection of human health, with all but one station rated as either as 'good'' or 'excellent' . Chau Doc was the only station rated as 'moderate' due to the reduced DO levels that violated WQGH (6 mg/L). Since there are no recorded violation of the guideline values for the Water Quality Index for General Irrigation and the Water Quality Index for Paddy Rice Irrigation, it

can be concluded that there was no restriction for all types of agricultural use of the Mekong and Bassac Rivers water. It should be noted, however, that water quality monitoring in the Mekong Delta was undertaken during low tide, and therefore, suitability of water for agricultural use may differ during the high tide.

In term of transboundary river pollution, while analyses of water quality data at Pakse/Stung Treng, Kaorm Samnor/Tan Chau, and Koh Thom/Chau Doc reveal significant differences of levels of NO_{32}, TOTN, and COD at these station with P values of less than 0.01, the levels were still well below the WQGH and the WQGA. However, the combined levels of these pollutants appear to have affected DO levels, in particular at Chau Doc, and should be further closely monitored to ensure that any further change that may have potential effects on human health and aquatic life are detected in a timely manner and remedial action is taken.

Introduction

2.1 Background

The Mekong River is the 12th longest river in the world, at about 4,880 km, and the 8th largest river in terms of mean annual discharge at its mouth, at about 14,500 m^3/s (Mekong River Commission, 2018). 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 (Mekong River Commission, 2018).

According to the 2018 State of the Basin Report (Mekong River Commission, 2018), the Lower Mekong River is home to about 70 million people, of whom about 85% live in rural areas where many practises subsistence farming, with supplemental fish catch for livelihoods and food security. The Mekong River is also one of the most bio-diverse rivers in the world with estimated 1,148 fish species (ibid). 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.

2.2 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) with the specific objective of detecting changes in the Mekong River water quality and ensuring that preventive and remedial actions are taken if any changes are detected. The routine monitoring and reporting of water quality are the main functions of the WQMN, which was established in 1985 with a funding support from the Swedish International Development Agency (Sida). During its inception phase, Sida also provided capacity building to the MCs to monitor water quality of the Mekong River and its tributaries in their respective national boundaries. 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 boundary.

As many as 90 water quality stations have been monitored as part of the WQMN. The peak sampling year was recorded in 2005 when 90 stations were monitored. In 2006, the MRC led by the Environment Programme, conducted a full assessment of water quality monitoring activities in the Mekong River under the WQMN. One of the outcomes of the assessment was the need to reduce the cost of the monitoring while at the same time increase its suitability. An agreement was reached for the Network to include only primary stations while the secondary stations would be monitored by individual MCs. Primary stations are those that are located in the mainstream and key tributaries of the Mekong River. Since 2006, 48 stations have been classified as 'primary stations' and were designed to detect changes and capture pressures and threats to Mekong water quality. A number of these stations were also strategically selected to detect transboundary water quality problems. In 2018, these stations continued to be monitored by the MCs as part of the WQMN. Of these 48 stations, 17 were located in the Mekong mainstream while the remaining stations (31) were located in the tributaries. Table 1 and Figure 1 in Section 12.1 details the locations of these stations.

Since its inception in 1985, the WQMN has provided a continuous record of water quality in the Mekong River and its tributaries by measuring a number of different water quality parameters at different stations. Up to 18 water quality parameters are monitored by the WQMN on a monthly basis, although during its peak years, between 1995 and 2004, up to 23 water quality parameters were monitored. These parameters comprise physical, chemical and bacteriological parameters.

The WQMN is one of the MRC's core river basin management function activities, which will be fully decentralised to the MCs by 2020. The decentralisation of the WQMN was completed for Thailand and Viet Nam in 2016 and for Cambodia in 2018. For Lao PDR, the decentralisation of the WQMN will be completed by 2025. Following decentralisation, MCs through their designated water quality laboratories will be required to finance and undertake the monitoring, sampling and analysis of Mekong water quality. At national level, each Member Country has designated a national water quality laboratory to undertake the monitoring, sampling, and analysis of Mekong water quality. The designated laboratories are responsible for undertaking routine monitoring and measurement of 19 water quality parameters (Table 3). They are also responsible for analysing, assessing and reporting water quality data on an annual basis. Their specific duties are to:

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

- produce and publish annual water quality data assessment report, outlining the results of water quality monitoring, analysis and assessment.

At the regional level, the MRCS is responsible to provide technical support for the monitoring of water quality and to ensure the integrity of data recorded at the national level. The MRCS also acts as a central hub for regional water quality data and provides a platform for data exchange in accordance with the 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 in the LMB.

2.3 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 both MRC Strategic Plan 2016–2020 and the Basin Development Strategy for 2016–2020. According to these documents, 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 available water quality guidelines as defined in the MRC Procedures for Water Quality and its technical guidelines. As such, the main objectives of this report are to:

- Provide the status of water quality in the Mekong River in 2018 by assessing water quality monitoring data monitored by the WQMN laboratories in 2018 and compare them with available MRC water quality guidelines;
- Identify any spatial changes observed in the water quality of the Mekong River in 2018;
- Identify any temporal changes observed in the Mekong River water quality at the 17 mainstream stations and 5 Bassac stations from the inception of their monitoring to 2018;
- Identify and discuss any transboundary water quality issue observed in 2018;
- Provide recommendations for future monitoring and continuous improvement of the water quality monitoring activities.

Materials and methods

2.1 Monitoring location and frequency

Forty-eight (48) stations were monitored by the WQMN in 2018. A breakdown of the number of stations in each Member Country is presented in Table 1. As can be seen in the table, of the 48 stations monitored in 2018, 11 stations are located in Lao PDR, 8 in Thailand, 19 in Cambodia and 10 in Viet Nam.

Figure 1 illustrates their locations in the Lower Mekong Basin (17 on the Mekong River, 31 on Mekong tributaries, in which 5 on the Bassac River and 26 on the others). The detailed list of each station, code name and coordinates can be found in Table 2.

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

Table 1. A summary of 2018 water quality monitoring stations

Countries	No. of stations	No. on the Mekong River	No. on tributaries		Monitoring frequency
			No. on the Bassac River	Others	
Lao PDR	11	5	0	6	Monthly
Thailand	8	3	0	5	Monthly
Cambodia	19	6	3	10	Monthly
Viet Nam	10	3	2	5	Monthly
Total	48	17	5	26	Monthly

Table 2 lists the 22 mainstream stations monitored in 2018 in geographical order, from upstream to downstream, to facilitate the analysis of water quality trends along the Mekong River mainstream.

Table 2. Water quality monitoring stations in the Mekong and Bassac Rivers numbered in sequence from upstream to downstream, and as recorded in 2018

Station no.	Name of station	Station ID	River	Countries	Latitude	Longitude
1	Houa Khong	H010500	Mekong River	Lao PDR	21.5471	101.1598
2	Chiang Saen	H010501	Mekong River	Thailand	20.2674	100.0908
3	Luang Prabang	H011200	Mekong River	Lao PDR	19.9000	102.0000
4	Vientiane	H011901	Mekong River	Lao PDR	17.9281	102.6200
5	Nakhon Phanom	H013101	Mekong River	Thailand	17.4250	104.7744
6	Savannakhet	H013401	Mekong River	Lao PDR	16.5583	104.7522
7	Khong Chiam	H013801	Mekong River	Thailand	15.3255	105.4937
8	Pakse	H013900	Mekong River	Lao PDR	15.1206	105.7837
9	Stung Treng	H014501	Mekong River	Cambodia	13.5450	106.0164
10	Kratie	H014901	Mekong River	Cambodia	12.4777	106.0150
11	Kampong Cham	H019802	Mekong River	Cambodia	11.9942	105.4667
12	Chrouy Changvar	H019801	Mekong River	Cambodia	11.5861	104.9407
13	Neak Loung	H019806	Mekong River	Cambodia	11.2580	105.2793
14	Kaorm Samnor	H019807	Mekong River	Cambodia	11.0679	105.2086
15	Tan Chau	H019803	Mekong River	Viet Nam	10.9079	105.1835
16	My Thuan	H019804	Mekong River	Viet Nam	10.2725	105.9100
17	My Tho	H019805	Mekong River	Viet Nam	10.3430	106.3505
18	Takhmao	H033401	Bassac River	Cambodia	11.4785	104.9530
19	Koh Khel	H033402	Bassac River	Cambodia	11.2676	105.0292
20	Koh Thom	H033403	Bassac River	Cambodia	11.1054	105.0678
21	Chau Doc	H039801	Bassac River	Viet Nam	10.9552	105.0867
22	Can Tho	H039803	Bassac River	Viet Nam	10.0580	105.7977

Figure 1. Water quality monitoring stations of the MRC WQMN in the Mekong River and its tributaries, 2018

2.2 Sampling techniques

In an effort to standardize the sampling techniques, in 2018, the MRC continued to work with the designated laboratories of the MCs to identify appropriate sampling techniques for

collecting water samples. Through consultations, it was agreed that the water sampling, sample preservation, sample transportation and storage, would be carried out in accordance with methods listed in the Technical Guidelines for the PWQ (TGWQ), which have been prepared in accordance with the 22nd edition of the Standard Methods for the Examination of Water and Wastewater (Rice et al., 2012) or in accordance with national standards complying with the requirements of method validation of ISO/IEC 17025-2005.

Specifically, the designated laboratories are required to:

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

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

2.3 Laboratory analytical methods

Since its inception in 1985, the Water Quality Monitoring Network has provided data on water quality in the Mekong River and its selected tributaries by measuring a number of different water quality parameters. At its peak, the network (Table 2) provided a measurement of 23 water quality parameters. However, in 2018, 19 water quality parameters were measured by the MRC WQMN (Table 3). Of the 19 parameters measured in 2018, 13 are routine water quality parameters that are required to be measured for each sample month. The other six, major anions and major cations, are required to be analysed for each sample taken between April and October.

In addition to providing a list of parameters measured by the MRC WQMN, Table 3 provides a list of recommended analytical methods used for measuring water quality parameters, as mentioned in Section 2.2.

Table 3. Water quality parameters and their corresponding analytical methods

Analytical parameter	Recommended analytical methods
Temperature	2550-Temp/SM
pH	4500-H^+/SM
Electrical conductivity	2510-EC/SM
Alkalinity/acidity	2320-A/SM
Dissolved oxygen (DO)	4500-O/SM
Chemical oxygen demand (COD)	Permanganate oxidation
Total phosphorous (T-P)	4500-P/SM

Total Nitrogen (T-N)	4500-N/SM
Ammonium (NH4-N)	4500-NH4/SM
Total nitrite and nitrate (NO2-3-N)	4500-NO2-3/SM
Faecal coliform	9221-Faecal coliform group/SM
Total suspended solids	2540-D-TSS-SM
Calcium (Ca)	3500-Ca-B/SM
Magnesium (Mg)	3500-Mg-B/SM
Sodium (Na)	3500-Na-B/SM
Potassium (K)	3500-K-B/SM
Sulphate (SO4)	4500- SO4 –E/SM
Chloride (Cl)	4500-Cl/SM
BOD_5	5210-BOD_5/SM

2.4 Data analysis

2.4.1 Status and trends

The overall status of the Mekong water quality in 2008 was examined by applying descriptive statistics such annual maximum, mean, and minimum to summarise data series of key water quality parameters collected in 2018 along the Mekong River. Descriptive statistics are commonly used to analyse and compare various aspects of water quality data (He et al., 2009; Johnson et al., 2009; Ai et al., 2015; Gu et al., 2019), as they provide quick snapshots of data series that are generally large and not event distributed in nature (Fisher and Marshall, 2009; Lee, 2020). These values were compared to those of the WQGH (Chapter 1 of the TGWQ) and for the Protection of Aquatic Life (Chapter 2 of the TGWQ) to identify any exceeded values that need special attention.

Variations of key water quality parameters were assessed spatially and temporally. Spatial variation was carried out for 2018 to examine the differences in levels of key water quality parameters along the Mekong and Bassac Rivers. Pearson correlation analyses (Benesty et al., 2009) were performed to establish relationships between these parameters and to help explained the variation observed.

Temporal analyses of water quality data from the period of 1985 to 2018 were carried out for key parameters using a combination of box-and-whisker plots and seasonal Mann-Kendall trend test (SKM) (Chang, 2008; Ly et al., 2020). Known as a non-parametric method, SKM has the advantage for its capabilities in handling environmental monitoring data series similar to those found in the water quality data series and have been used to detect trends for data series that exhibit seasonality, missing data point and non-normal distributed (Fu and Wang, 2012; Ly et al., 2020).

In addition to these statistical analyses box-and-whisker plots were used to help support the characterization of water quality data, for both spatial and temporal analyses. Box-and-whisker plots are often used to analyse variation and central tendency of data. It is a useful

statistical tool, which can be used to explore a dataset and show key statistics associated with it. In particular, when using box-and-whisker plots the following key statistical information can be drawn (Fu and Wang, 2012):

- median value of the dataset;
- upper quartile and lower quartile or the median of all data above and below the median, respectively;
- upper and lower extremes or the maximum and minimum values of the dataset (excluding outliers), respectively.

2.4.2 Transboundary water quality

Transboundary water quality was assessed for six stations located at or near national borders of the MCs. Water quality data comparison and assessment were made for Pakse versus Stung Treng; Kaorm Samnor versus Tan Chau; and Koh Thom versus Chau Doc. Comparisons were made for two stations using key pollutant monitoring data in 2018 for the stations closest upstream and downstream of the national border, respectively. Box-and-whisker plots, using the statistical software package SPSS 23, were used to characterise water quality data. Any observed differences between the upstream and downstream stations were tested using an independent t-test, to determine whether the differences observed are statistically significant.

2.4.3 Water quality indices

Another way to assess water quality in the Mekong River is through the use of the MRC Water Quality Indices, which combine the results of several parameters into one overall value describing the water quality. In 2013, the MRC MCs adopted three water quality indices taking into account requirements under Chapters 1 and 2 of the TGWQ and available water quality guidelines of the MCs. These indices include:

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

The Water Quality Index for the Protection of Aquatic Life

The Water Quality Index for the Protection of Aquatic Life is calculated using **Equation 2.1**. The Index was developed as an open-ended index, which would allow more parameters to be added once data become available (Campbell, 2014). In this annual water quality report, only six parameters are included. These parameters, together with their target values, are listed in Table 4. The classification system for the Water Quality Index for the Protection of Aquatic Life is summarized in Table 5.

$$WQI = \frac{\sum_{i=1}^{n} p_i}{M} \times 10$$ Equation 2.1

Where,

"p_i" is the points scored on sample day i. If each parameter listed in Table 4 meets its respective target value in Tables 2–6, 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 4. Parameters used for calculating the rating score of the Water Quality Index for the Protection of Aquatic Life, together with their target values

Parameters	Target values
pH	6–9
EC (mS/m)	< 150
NH_3 (mg/L)	0.1
DO (mg/L)	≥5
NO_{2-3} – N (mg/L)	0.5
T-P (mg/L)	0.13

Table 5. Rating systems for the Water Quality Index for the Protection of Aquatic Life

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

Water Quality Index for the Protection of Human Health

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

The Human Health Acceptability Index utilizes parameters of indirect impact, as identified by the Water Quality Index for Human Health (HH), while the Human Health Risk Index utilizes direct impact parameters. The rating score for both indices can be calculated using **Equation**

2.2, which is based on the Canadian Water Quality Index (CCME, 2001). It should be noted that since the monitoring of direct impact parameters has not commenced, MCs have agreed to adopt only the Human Health Acceptability Index. The list of the approved parameters to be included in the calculation of the rating score for the human health acceptability index, together with their target values are listed in Table 6. The classification system for the Water Quality Index for the Protection of Human Health – Human Acceptability Index is summarized in Table 7.

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

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

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

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

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

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

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

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

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

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

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

Table 6. Parameters used for calculating the rating score of the Water Quality Index for the Protection of Human Health and with their target values

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

**Due to the required holding time for Biochemical oxygen demand (BOD), MCs have agreed to only monitor BOD at stations where samples can be analysed within the required holding time of less than 48 hours. Therefore, BOD was only included for the stations where data are available.*

Table 7. Rating systems for the Water Quality Index for the Protection of Human Health

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

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 irrigation and paddy rice. The indices for general irrigation and paddy rice are calculated based on the MRC Water Quality Guidelines for Salinity (electrical conductivity). The electrical conductivity (EC) guidelines, together with the degree of consequence, for the indices for general irrigation and paddy rice irrigation are outlined in Table 8.

Table 8. Electrical conductivity guidelines and degrees of consequence for Water Quality Index for Agricultural Use – general irrigation and paddy rice

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

Note:

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

2.5 Quality assurance/quality control

Recognizing the need to improve the quality, precision and accuracy of the water quality data, all designated laboratories of the MRC WQMN were requested to jointly implement a quality assurance and quality control (QA/QC) test for water sampling, preservation, transportation,

and analysis from 2004. The goal of the implementation of the QA/QC procedures is to ensure that the designated laboratories carry out their routine water quality monitoring activities in accordance with the TGWQ and international standard ISO/IEC 17025-2005. To date, of the four designated laboratories of the MRC WQMN, the laboratories in Lao PDR and Viet Nam have received ISO/IEC 17025-2005 certification. The certifications were given by the Bureau of Accreditation, Directorate for Standards and Quality of Viet Nam.

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

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

Results

3.1 Water quality status and trend

Water quality data from the WQMN has allowed for relationships between key water quality parameters to be established (**Table 9**). These relationships are important in facilitating the understanding of instream behaviours of key water quality parameters. For example, nitrate-nitrite ($NO_{32}N$) levels in the Mekong appear to be positively correlated with TOTN and chemical oxygen demand (COD) while negatively correlated with ammonium (NH_4N), total phosphorus (TOTP), and dissolved oxygen (DO); i.e. as TOTN and COD levels increased, so did the levels of NO_{32}. Conversely, the decrease in $NO_{32}N$ levels were due to the increase in NH_4N, TOTP and DO levels.

Key water quality parameters monitored in stations along the Mekong and Bassac Rivers are analysed spatially and temporally to reflect the status of water quality of the LMB in 2018 and the trend of water quality from 2000 to 2018. In addition, a comparison of the maximum, mean, and minimum values of key water quality parameters between 1985–2017 and 2018 are presented in Tables 10 and to see if there is any parameter exceeding the WQGH and the WQGA. Four of the nine key parameters monitored in 2018 violated the MRC water quality guidelines listed in Chapters 1 or 2 of the TGWQ at one point or another in stations along the Mekong River (Table 10). These parameters were: (i) pH with minimum value of 5.4 compared to the recommended guidelines of 6 to 9; (ii) EC with values ranging from 4.6 to 50.7 mS/m compared to the recommended guidelines of 70–150 mS/m; (iii) DO with a minimum value of 4.57 mg/l, which did not meet the required guidelines for both the protection of human health (6 mg/L) and aquatic life (5 mg/L); and (iv) COD with maximum value of 6.48 mg/L, which exceeded the WQGH (5 mg/L). Along the Bassac River, three key parameters were recorded to have violated the same guidelines. These parameters included: EC, where all recorded values fell outside the guidelines range of 70 –150 mS/m; DO with a minimum value of 3.1 mg/L, which did not reach the recommended WQGH (6 mg/L) and the WQGA (5 mg/L); and COD, which exceeded the guidelines for the protection of human health (5 mg/L), with the maximum recorded value of 5.6 mg/L.

Table 9. Relationships between key water quality parameters in the Mekong River as monitored by the WQMN, 1985 to 2018

pH	TSS (mg/L)	EC (mS/m)	$NO_{32}N$ (mg/L)	NH_4N (mg/L)	TOTN (mg/L)	TOTP (mg/L)	DO (mg/L)	CODMN (mg/L)	
1	-0.004	.125*	.189**	-.168**	0.073	-.146*	.148*	-0.028	pH
	1	-.177**	-0.038	-0.058	-0.047	.316**	0.088	.233**	TSS (mg/L)
		1	.352**	-.294**	.263**	-.417**	.194**	-0.078	EC (mS/m)
			1	-.200**	.563**	-.150*	-.197**	.395**	$NO_{32}N$ (mg/L)
				1	-0.026	.178**	-0.077	-0.003	NH_4N (mg/L)
					1	-0.011	-.178**	.405**	TOTN (mg/L)
						1	-0.049	0.058	TOTP (mg/L)
* Correlation is significant at the 0.05 level (2-tailed).							1	-.500**	DO (mg/L)
** Correlation is significant at the 0.01 level (2-tailed).								1	CODMN (mg/L)

Table 10. Comparison of water quality data in the Mekong River, between 1985–2017 and 2018

Parameters	Unit	Water Quality Guidelines		1985–2017				2018			
		Protection of Human Health (WQGH)	Protection of Aquatic Life (WQGA)	Max	Mean	Min	Stdev	Max	Mean	Min	Stdev
pH	-	6 – 9	6 – 9	9.9	7.5	3.8	0.5	8.5	7.4	5.4*	0.5
TSS	mg/L	-	-	5716.0	147.1	0.1	256.2	518.0	84.9	2.8	91.9
EC	mS/m	70 –150	-	841.0	20.7	1.2	27.7	50.7	19.8	4.6	6.6
$NO_{32}N$	mg/L	5	5	1.42	0.24	0.00	0.17	1.12	0.31	0.03	0.19
NH_4N	mg/L	-	-	2.99	0.05	0.00	0.11	0.36	0.07	0.00	0.07
TOTN	mg/L	-	-	4.89	0.58	0.00	0.39	3.56	0.56	0.11	0.32
TOTP	mg/L	-	-	2.20	0.10	0.00	0.12	0.43	0.09	0.00	0.08
DO	mg/L	≥ 6	> 5	13.85	7.22	2.25	1.09	11.43	6.60	4.57	1.11
CODMN	mg/L	5	-	65.00	2.25	0.00	1.97	6.48	2.47	0.13	1.50

Note:

*Yellow colour marks non-compliance with WQGH or WQGA.

Table 11. Comparison of water quality data in the Bassac River, between 1985–2017 and 2018

Parameters	Unit	Water Quality Guidelines		1985–2017				2018			
		Protection of Human Health (WQGH)	Protection of Aquatic Life (WQGA)	Max	Mean	Min	Stdev	Max	Mean	Min	Stdev
pH	-	6–9	6–9	8.0	7.1	6.2	0.4	8.1	7.2	6.6	0.3
TSS	mg/L	-	-	279.0	58.0	4.5	49.6	218.9	46.8	2.9	42.1
EC	mS/m	70–150	-	27.5*	14.7	7.5	4.8	24.8	15.8	9.8	5.1
$NO_{32}N$	mg/L	5	5	1.10	0.31	0.02	0.21	1.09	0.33	0.03	0.25
NH_4N	mg/L	-	-	0.63	0.11	0.00	0.11	0.42	0.10	0.01	0.07
TOTN	mg/L	-	-	3.45	0.75	0.15	0.49	1.52	0.59	0.25	0.29
TOTP	mg/L	-	-	1.24	0.15	0.00	0.14	0.32	0.12	0.01	0.07
DO	mg/L	≥ 6	> 5	9.3	6.3	1.8	1.1	7.5	5.7	3.1	0.8
CODMN	mg/L	5	-	5.9	2.7	0.3	1.2	5.6	2.9	0.4	1.4

Note:

*Yellow colour marks non-compliance with the WQGH or the WQGA.

3.1.1 pH

In aquatic ecosystems, pH can affect many chemical and biological processes. This is because pH affects the solubility and availability of nutrients and heavy metals in water (USEPA, 2012b). At extremely low pH, some toxic compounds and elements from sediments may be released into the water where they can be taken up by aquatic animals or plants, and ultimately by humans through direct contact and/or human consumption of aquatic animals or plants (USEPA, 2012b). Additionally, changes in pH can also influence the availability of trace elements, iron and nutrients, such as phosphate and ammonia in water. As such, pH is one of the key water quality parameters monitored by the MRC Water Quality Monitoring Network. In 2018, the WQMN continued to monitor pH levels at all 17 Mekong and 5 Bassac water quality monitoring stations.

Recognizing the importance of pH on the Mekong riverine environment, the MCs have agreed to establish the technical water quality guidelines for pH levels in the Mekong River and its tributaries to protect human health and aquatic life. The overall goal is to achieve the MRC water quality – i.e. to maintain acceptable/good water quality to promote the sustainable development of the Mekong River Basin.

Compared to the recommended guidelines, the results of 2018 monitoring revealed that, while all pH values measured along the Bassac River were within the upper and lower target values of the WQGH and the WQGA (pH values of 6 to 9 for both the protection of human health and aquatic life), 1.5% of pH values measured along the Mekong River were lower, the same recommended target values (Tables 10 and 11).

In 2018, the pH values recorded in the Mekong ranged from 5.4 to 8.5, with the minimum pH value recorded at Luang Prabang Station in Lao PDR, on 17 July 2018, and the maximum value measured in Houa Khong Station, on 16 August 2018. The average pH value of the Mekong River in 2018 was recorded at about 7.4, which was similar to the average values recorded between 1985 and 2017 (pH of 7.5).

The spatial trend for pH in the Mekong and Bassac Rivers is shown in Figure 2. Other than the level observed in Luang Prabang ($5.4 \leq pH \leq 7.9$), pH levels did not greatly vary from station to station. Results of the temporal analysis of pH data from 1985 to 2018 are shown in Figure 3. Figure 3 shows that the overall pH levels decreased slightly from 1985 to 2018. In 1985, the average pH value was recorded at 7.8, while in 2018, the average pH value was recorded at 7.3.

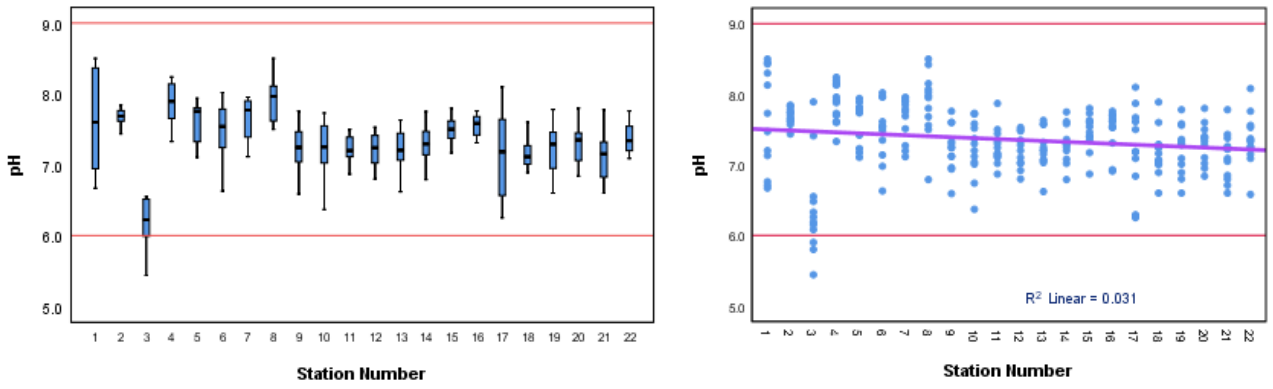


Figure 2. Spatial variation in pH levels along the Mekong River (Stations: 1–17) and Bassac River (Stations: 18–22) as recorded in 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

Note:

The horizontal lines at 6.0 and 9.0 represent the lower and upper pH limits of the WQGH and the WQGA, respectively.

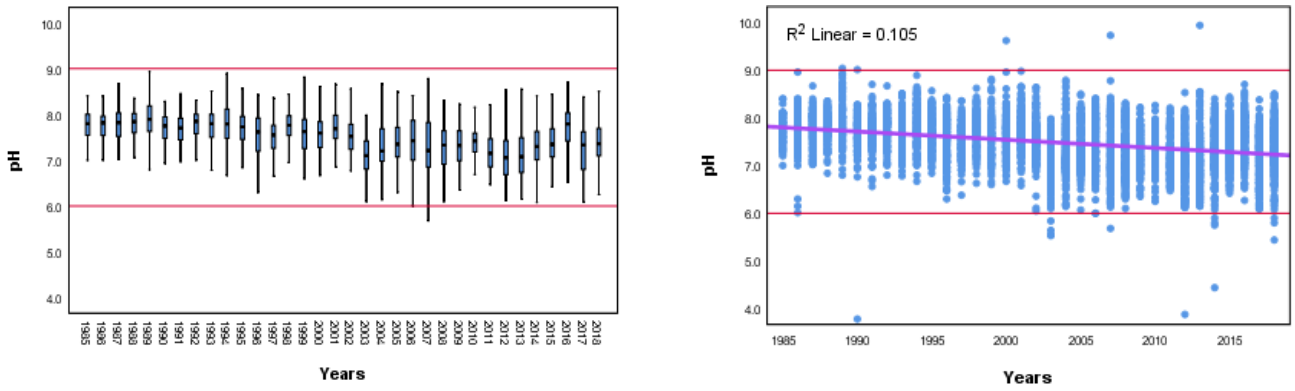


Figure 3. Temporal variation in pH levels in the Mekong River, 1985–2018, and illustrated using box-and-whisker plot (left) and dot plot (right)

Note:

The horizontal lines at 6.0 and 9.0 represent the lower and upper pH limits of the WQGH and the WQGA, respectively.

3.1.2 Electrical conductivity

Electrical conductivity (EC) is another useful water quality indicator monitored by the MRC WQMN. It provides a valuable baseline that has been used to identify any emerging effects of development on water quality in the Mekong River. Under normal circumstance and in areas that are not affected by saline intrusion, the Mekong and Bassac Rivers, similar to other water bodies, have constant ranges of conductivity, and therefore, any sudden and significant change in EC can be an indicator of water pollution. Wetzel (2001) states that pollution from

agricultural runoff or sewage leaks can increase EC levels, while USEPA (2014) reported that a spill of organic compound such as oil can reduce them.

In 2018, all EC levels were recorded to fall outside the recommended range of the WQGHof 70–150 mS/m. It should be noted, however, that the Mekong River mainstream and Bassac River are naturally a low-salinity river with EC values rarely exceeded 50 mS/m. High EC had been observed in the Delta (Viet Nam's stations) during high tide due to the intrusion of sea water, and had been recorded with a maximum value of 841.0 mS/m. This maximum value was recorded at My Tho Water Quality Monitoring Station in April 1998. In 2018, all samplings in the Delta, for both the Mekong River and the Bassac Rivers, were carried out during low tide, which may explain the low levels of EC recorded.

Spatial and temporal trends for EC in the Mekong and Bassac Rivers are illustrated in **Figures 4** and **5**, respectively. The Mekong and Bassac Rivers can generally be characterised as rivers with low conductivity values, with average historical values from 1985 to 2017 of about 20.7 and 14.7 mS/m, respectively (**Tables 10** and **11**).[1] In 2018, ECs of the Mekong River were not different from the historical values with the mean value of 19.8 mS/m. For the Bassac River, the conductivity continued to be relatively low, with values ranging from 9.8 to 24.8 mS/m, and the mean value was 15.8 mS/m, which is similar to the historical values (**Table 11**).

Spatially, as shown in **Figure 4**, in 2018, conductivity levels in the Mekong River were not very different among stations. The highest value was recorded in the upper part of the river. For example, Houa Khong Station (1), the uppermost station of the MRC WQMN, reported EC values ranging from 20.1 to 32.8 mS/m, with an average value of 27.3 mS/m. At My Tho Station (17) – the last station in the Mekong River before the river enters the East Sea – reported values ranged from 13.6 to 50.7 mS/m, with an average value of 22.5 mS/m. Chrouy Changvar (12), the station located in the middle part of the Lower Mekong River, reported values ranging from 10.3 to 23.7 mS/m, with an average value of 17.3 mS/m.

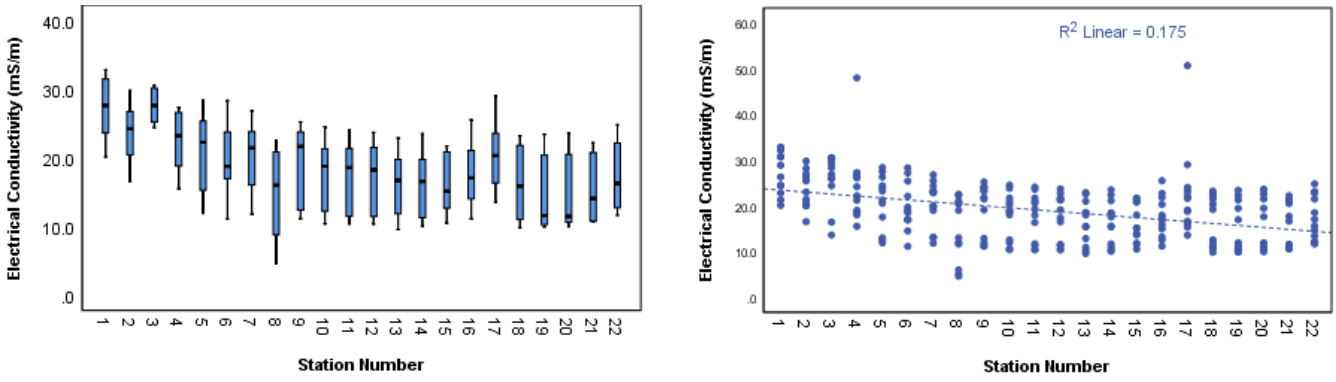


Figure 4. Spatial variation in electrical conductivity levels along the Mekong River (1–17) and Bassac River (18–22) as recorded in 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

[1] These average values are based on measurements taken during low tide. Electrical conductivity values for stations located in the Delta generally can reach up to more than 5,000 mS/m during high tide.

Note:

The horizontal lines at 70 and 150 represent the lower and upper EC limits of the WQGH.

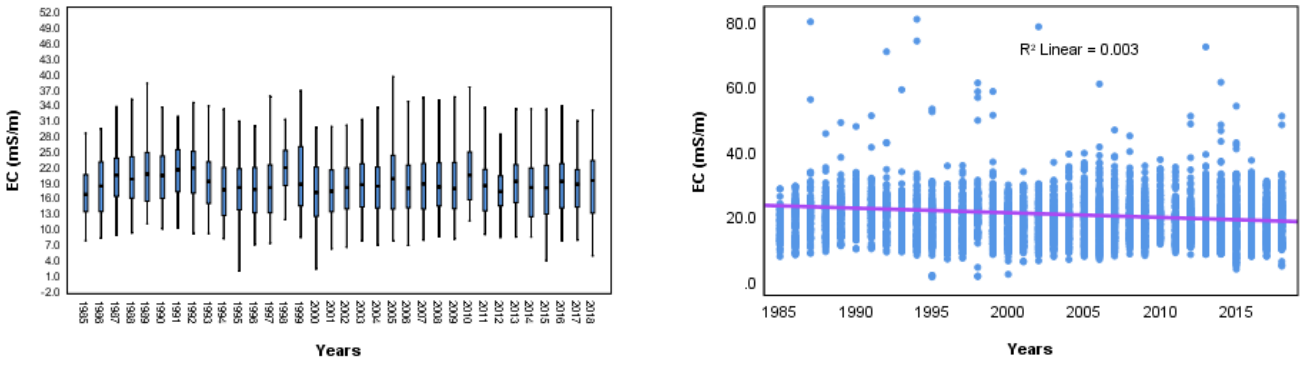


Figure 5. Temporal variation in electrical conductivity levels in the Mekong River as observed from 1985 to 2018 **and illustrated using box-and-whisker plot (left) and dot plot (right)**

Note:

The horizontal lines at 70 and 150 represent the lower and upper EC limits of the WQGH.

3.1.3 Total suspended solids

In the Mekong River, total suspended solids (TSS) are influenced by both natural and anthropogenic activities in the Basin, including urban runoff, industrial effluents, and natural and/or human induced (i.e. agriculture, forestry or construction) soil erosion (Herngren et al., 2005; Chen and Chang, 2014; Ly et al., 2020). The method used by the MRC WQMN to sample TSS does not reflect the sediment concentration in the entire water column,[2] but currently provides an indication of long-term trends in sediment content in the Mekong River.

In 2018, the TSS concentrations observed along the Mekong River continued to be highly variable, with values ranging from 2.8 to 518.0 mg/L. The average TSS concentration was about 84.9 mg/L (Table 10). TSS concentrations along the Bassac River, however, were less variable than the range observed along the Mekong River. Along the Bassac River, TSS concentrations ranged from 2.9 to 218.9 mg/L, with an average value of 46.8 mg/L (Table 11).

Spatially, the highest TSS levels were observed in the upper part of the Lower Mekong River. TSS levels at stations located in this part of the river were also highly variable, as can be seen in Figure 6. The maximum TSS concentration of 518 mg/L recorded in 2018 was observed at Luang Prabang, Lao PDR (3) in August 2018.

For both the Mekong and Bassac Rivers, the lowest TSS concentrations were observed during the dry season (November to April). In general, the Lower Mekong River receives very little to no rainfall during the dry season, which causes the dry season TSS concentrations to be lower than those generally observed during the wet season. Along the Mekong River, the average

[2] Water samples are taken approximately 30 cm below the water surface.

dry season TSS concentration was recorded at about 48.2 mg/L. The highest dry season concentration for TSS was recorded at 88.5 mg/L at Houa Khong Water Quality Monitoring Station, Lao PDR (1) in November 2018, while the lowest concentration was recorded at 4.6 mg/L at Kratie Water Quality Monitoring Station, Cambodia (10) in February 2018.

During the wet season, the average concentration for the Mekong River was recorded at about 138 mg/L, with values ranging from 19.3 to 518 mg/L. The lowest wet season TSS concentration was recorded in Chiang Sean, Thailand (2) in May 2018, while the highest concentration was recorded at Luang Prabang, Lao PDR (3) in August 2018.

The temporal analysis of data from 1985 to 2018 suggests that TSS levels in the Mekong River decreased since 2000 (Figure 7). The average TSS concentration in the Mekong River in 1985 was measured at about 388 mg/L, whereas in 2018, the average monthly concentration for TSS was measured at about 84.9 mg/L. This figure is slightly lower than the figure recorded in 2017, where the average TSS concentration for the Mekong River as recorded at 94.6 mg/L.

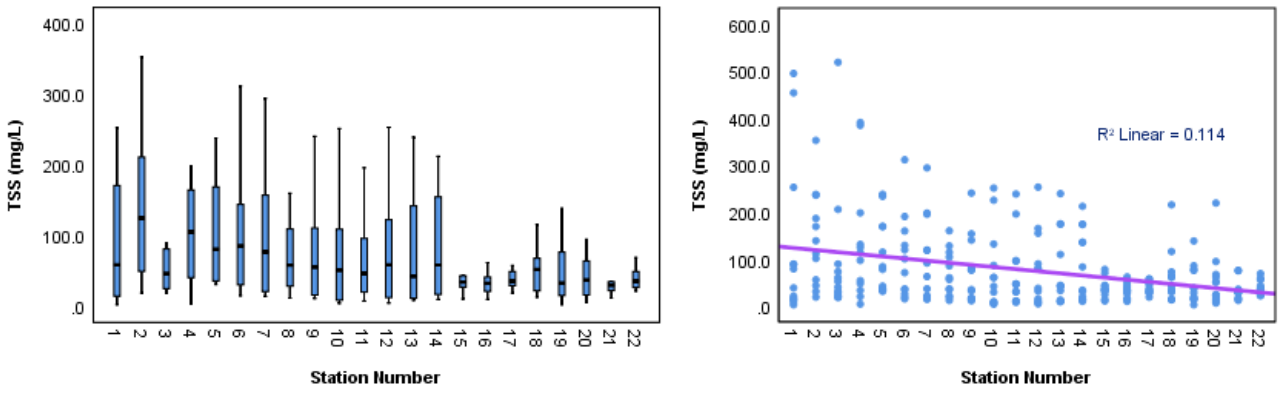


Figure 6. Spatial variation in TSS concentrations along the Mekong River (1–17) and Bassac River (18–22) as recorded in 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

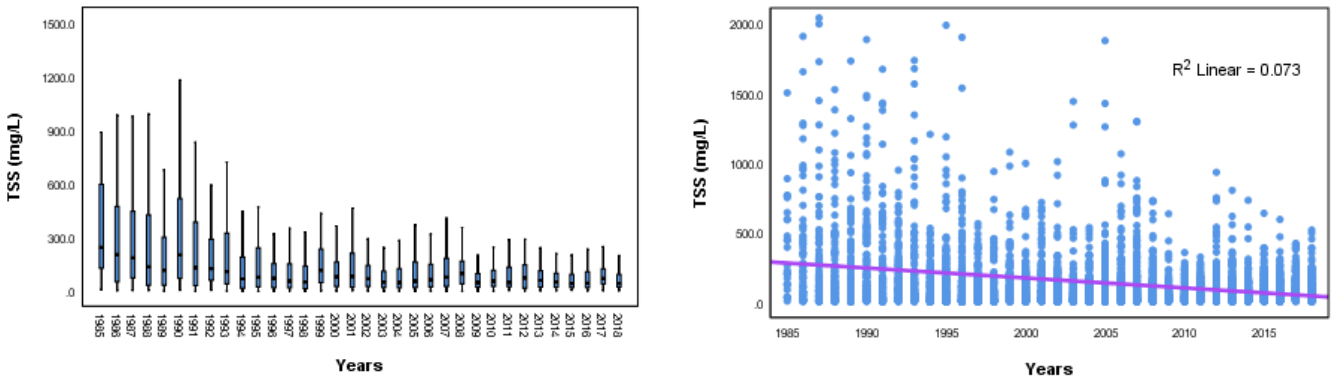


Figure 7. Temporal variation in TSS concentrations along the Mekong River as recorded from 1985 to 2018 **and illustrated using box-and-whisker plot (left) and dot plot (right)**

3.1.4 Nutrients

Nitrogen

The MRC WQMN designated laboratories continued to monitor concentrations of nitrite-nitrate, ammonium and total phosphorus as part of nutrient monitoring in 2018. Concentrations of nutrients at all mainstream stations in the Mekong River and Bassac River remained well below the WQGH and the WQGA (Table 10).

The spatial analysis of water quality data shows that in 2018, nitrate-nitrite concentrations were highly variable in a number of stations, including Houa Khong (1) and Savannakhet (6), which are located in the upper and middle part of the river, respectively, and My Tho (17), Chau Doc (21), and Can Tho (22), which are located in the Mekong Delta. At these stations, the highest concentration of nitrate-nitrite were observed at My Tho station in April 2018 at 1.12 mg/L, which was well below the MRC Water Quality Guidelines for the Protection of Human Health and Aquatic Life (5 mg/L) (Figure 8).

Temporal analysis of nitrate-nitrite concentration from 1985 to 2018 reveals that nitrate-nitrite concentrations in the Mekong River remained relatively constant (Figure 9). For the Mekong River, nitrate-nitrite concentrations in 2018 (average value of 0.31) were similar to those recorded in 2017 (average value of 0.32 mg/L), but slightly increased when compared to the concentrations recorded in 1985 (average 0.2). However, these values are well below the target values for both WQHGH and WQGA of 5 mg/L.

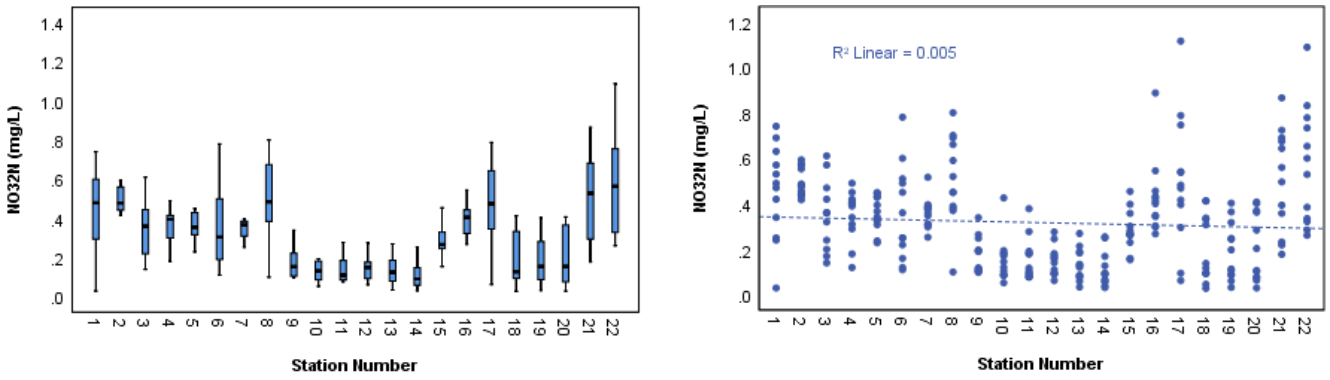


Figure 8. Spatial variation in nitrate-nitrite concentrations in the Mekong River (1–17) and Bassac River (18–22), 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

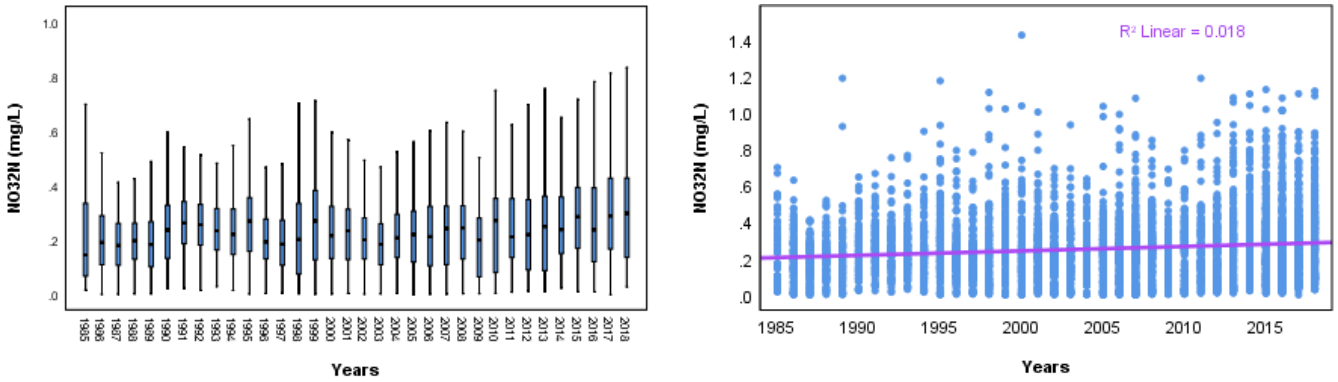


Figure 9. Temporal variation in nitrate-nitrite concentrations in the Mekong River as recorded in 1985–2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

Spatial analysis shows that the concentrations of ammonium along the stations in lower part of the basin including stations located along the Mekong and Bassac River were highly variable compared to those located in the upper part of the basin (Figure 10). In 2018, the highest ammonium was measured at Kampong Cham (11) (0.36 mg/L) and Koh Khel (19) (0.42 mg/L), for the Mekong and Bassac Rivers, respectively. At these stations, the average ammonium concentrations were recorded at 0.05 mg/L (Kampong Cham) and 0.12 mg/L (Koh Khel). In comparison, the threshold value used for calculating Water Quality Index for Human Impact is 0.05 mg/L.

A temporal analysis of data from 1985 to 2018 for the Mekong River reveals that overall ammonium concentrations remain relatively constant (Figure 11). The average yearly ammonium concentrations in the Mekong River increased slightly from 0.03 mg/L in 1985 to about 0.07 mg/L in 2018.

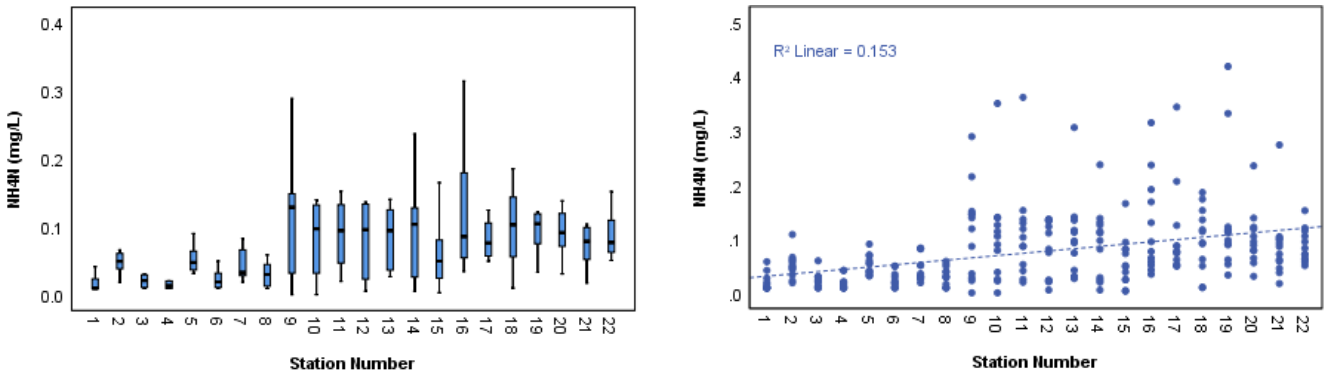


Figure 10. Spatial variation in ammonium concentrations in the Mekong River (1–17) and Bassac River (18–22), 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

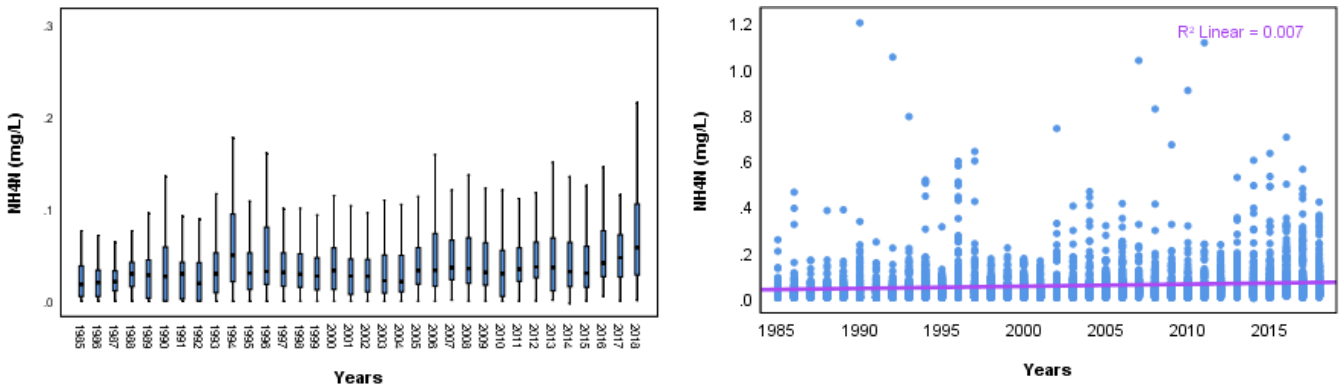


Figure 11. Temporal variation in ammonium concentrations in the Mekong River, as recorded in 1985–2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

Phosphorus

In 2018, total phosphorus concentrations were highly variable among stations (**Figure 12**). While the highest concentrations of total phosphorus were recorded at Houa Khong station (1) with the value of 0.43 mg/L, the lowest was observed at 0.04 mg/L at Kratie (10). Compared to the threshold value used for calculating the Water Quality Index for the Protection of Aquatic Life (0.13 mg/L) (**Table 4**), elevated concentrations of total phosphorus were observed at all but three monitoring stations on at least one monitoring occasion. The three monitoring stations were Luang Prabang (3), Vientiane (4), and Pakse (8) where in April no exceedance was recorded. In comparison, four stations recorded no concentration of greater than or equal to 0.13 mg/L in 2017.

In the Bassac River, the highest total phosphorus concentrations were recorded at stations in Cambodia was measured at Takhmao station (18) (0.29 mg/L), Koh Khel (19) (0.29 mg/L), and Koh Thom (20) (0.32 mg/L). Elevated concentrations of total phosphorus were observed at all monitoring stations in Bassac River on at least one monitoring occasion.

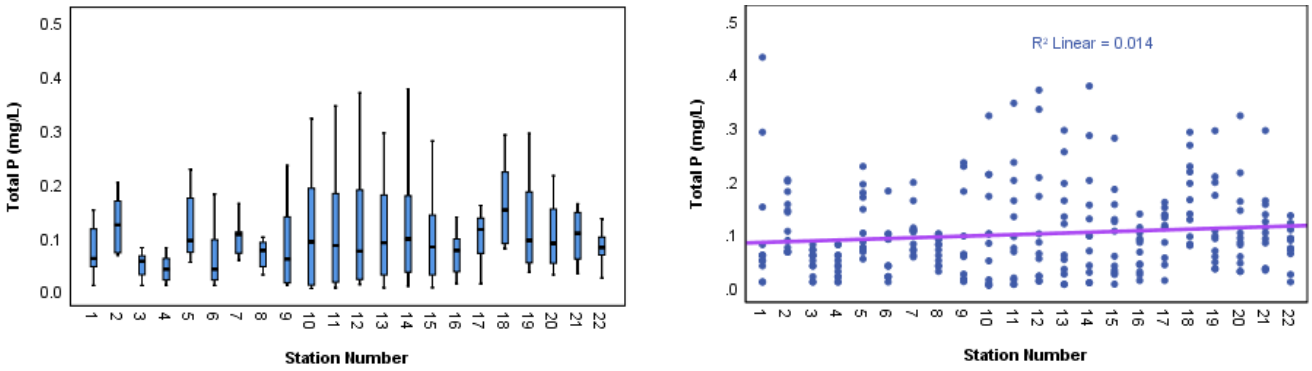


Figure 12. Spatial variation in total phosphorus concentrations in the Mekong River (1–17) and in the Bassac River (18–22) in 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

Between 1985 and 2018, total phosphorus concentrations in the Mekong River increased slightly, from mean concentration of about 0.1 mg/L in 1985 and 0.058 mg/L in 1986 to about 0.09 mg/L in 2018 (Figure 13). Increased human activities such as agricultural runoff and municipal wastewater discharge in the downstream part of the basin were the likely reason for the trend. However, the average concentration of total phosphorous in 2018 was similar to 2017 (0.1 mg/L).

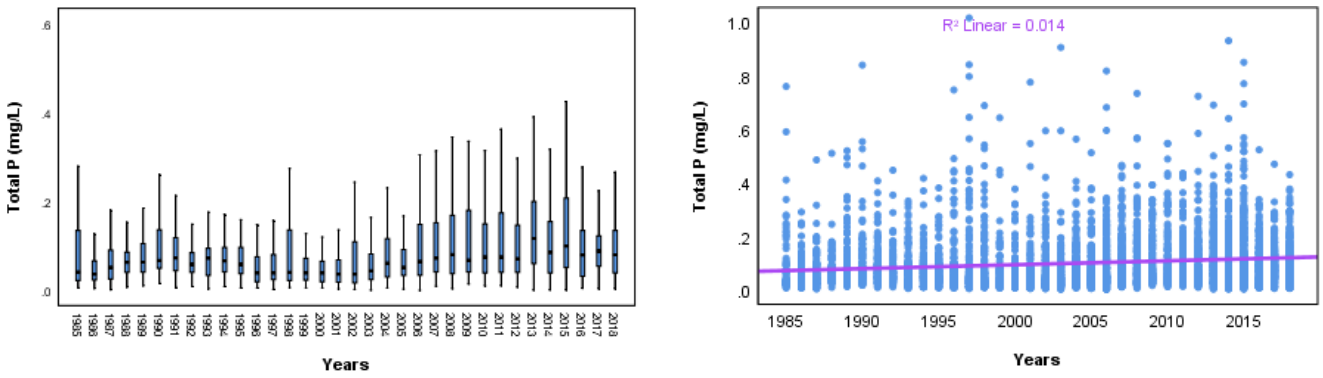


Figure 13. Temporal variation in total phosphorus concentrations in the Mekong River as observed from 2000 to 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

3.1.5 Dissolved oxygen

Dissolved oxygen (DO) is one of the key water quality parameters monitored routinely by the MRC Water Quality Monitoring Network. To maintain acceptable/good water quality, an adequate concentration of DO is necessary, because oxygen is required for all life forms, including those that live in a river ecosystem. Prolonged reduction in DO level can lead to fish kill, and can affect other water quality indicators, including biochemical and aesthetic indicators such as odour, clarity, and taste (USEPA, 2012a). Recognizing that DO is an integral component for determining the water quality of the Mekong River, the MRC MCs have jointly

established target values for the protection of human health (WQGH) (≥ 6 mg/L) and aquatic life (WQGA) (> 5 mg/L).

The 2018 DO data were compared with the MRC Water Quality Guidelines for the Protection of Human Health and Aquatic Life. Of the WQGH water quality monitoring stations located in the Mekong and Bassac Rivers, 14 stations recorded DO levels below the MRC Water Quality Guidelines for the Protection of Human Health at least once in the year (≤ 6 mg/L). In comparison, 15 stations recorded DO levels below the WQGH in 2017. This indicates a slight improvement in the concentrations of DO in the mainstream of the Mekong and Bassac Rivers.

In addition to violating the WQGH, eight stations recorded DO levels lower than the WQGA (i.e.< 5 mg/L), at least one time. These stations are all located in the Delta areas below Phnom Penh.

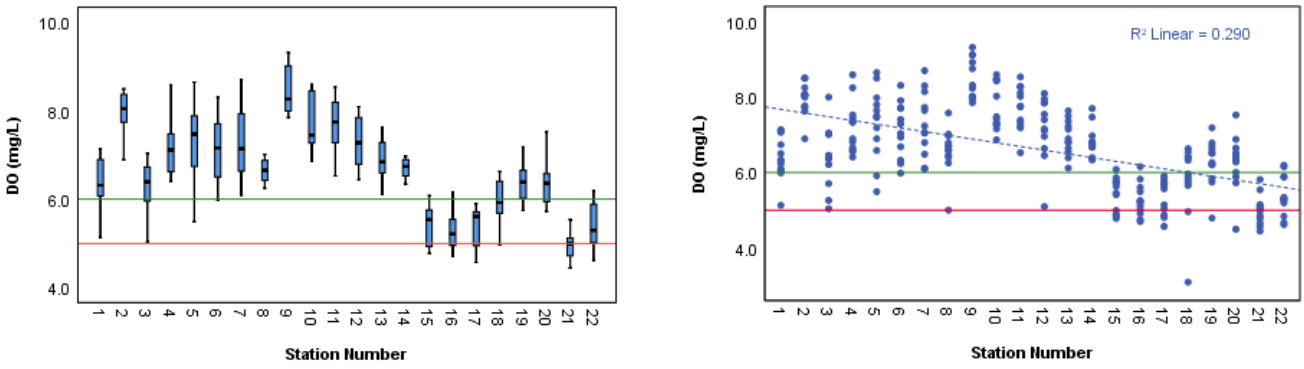


Figure 14. Spatial variation in DO (mg/L) at 22 stations along the Mekong River (1–17) and the Bassac River (18–22), 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

Note:
The horizontal lines at 5.0 (red) and 6.0 (green) represent DO target values of the WQGH and the WQGA, respectively.

The analysis of the spatial variation of 2018 DO data along the mainstream reveals that, on average, DO concentrations tended to be higher in the upper and middle section of the Mekong River (Figure 14). In 2018, the highest DO value in the Mekong River was observed at Chiang Sean (2) at 11.4 mg/L, Stung Treng (9) at 9.3 mg/L, Vientiane (4) at 8.6 mg/L. The lowest DO value was observed at My Tho (17) Takhamao monitoring station (4.5 mg/L). Along the Bassac River, the highest DO concentration was recorded in Koh Thom (20) at 7.5 mg/L in July 2018, whereas the lowest DO value was recorded at Takhamao monitoring station (18) at 3.1 mg/L in March 2018.

At Takhamao Water Quality Monitoring Station (21), more than 58% of DO values were lower than the MRC WQGH of 6 mg/L; compared to 2017, only 25% of the DO values at this station were lower than 6 mg/L.

A temporal analysis of DO in the Mekong River from 1985 to 2018 (Figure 15) reveals that DO concentrations in the mainstream decreased. In 1985, the average DO level was recorded at about 7 mg/L. This value had decreased to about 6.9 mg/L in 2018. The reduction appears to be related to the increased levels of COD, NO_{32}, NH_4^+, TOTN and TOTP, with significant relationships detected with NO_{32}, NH_4, and COD (Table 9).

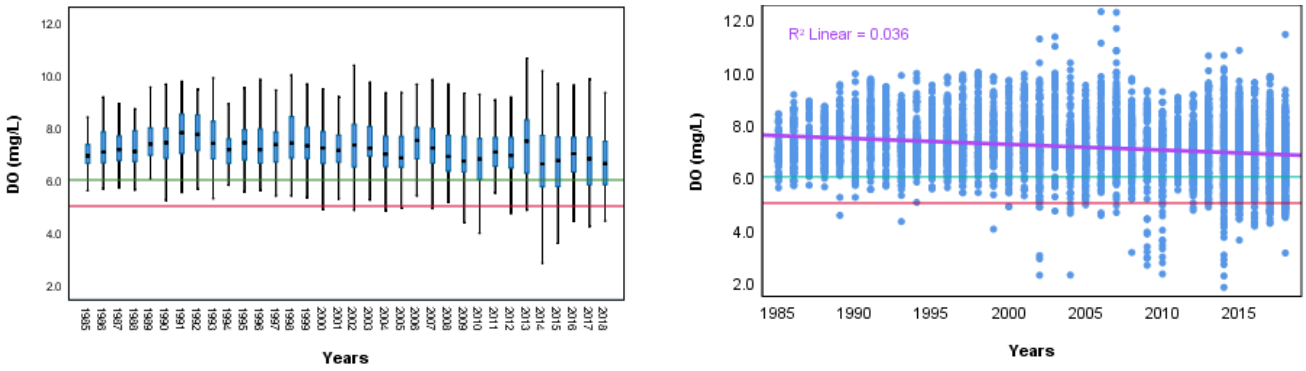


Figure 15. Temporal variation in dissolved oxygen (mg/L) in the Mekong River as recorded from 1985 to 2018

Note:
The horizontal lines at 5.0 (red) and 6.0 (green) represent DO target values of the WQGH and the WQGA, respectively.

3.1.6 Chemical oxygen demand

The amount of oxygen needed to oxidise organic and inorganic material is called chemical oxygen demand (COD), but in most cases, organic components predominate and are more significant (USEPA, 2012a; Lee et al., 2016). In July 2018, the maximum COD concentration in the Mekong River was recorded, at Khong Chiam Water Quality Station, at 6.48 mg/L. The value is slightly higher than the recommended WQGH (5 mg/L). In general, the COD levels were highest in the upper and Delta part of the river. Levels at stations in these parts of the river are also highly variable compared to those of stations located in the middle section of the river (Figure 16). The lowest COD value was recorded at Stung Treng (0.13 mg/L) (9) in June 2018. Overall, only about 7% of the total COD sampling occasions captured levels that were greater than 5 mg/L (WQGH), contributing to an overall low average COD values in 2018 (2.47 mg/L). Individually, seven stations recorded COD values exceeding the WQGH of 5 mg/L at least once in 2018. In comparison, an analysis of 2017 COD data reveals that only five stations recorded COD values higher than the threshold value of the MRC WQGH (5 mg/L). No COD threshold value has been set for the WQGA.

Figure 16 shows spatial variations in COD along the Mekong and Bassac Rivers in 2018. As can be seen in the figure, COD concentrations fluctuate as the river runs from upstream to

downstream, with the lowest and less variable concentrations recorded in the middle section of the river (where, accordingly, DO was found to be highest). The spatial trends of COD appeared to be directly opposite of that of DO, which further confirm the negative relationship of the two parameters as illustrated in Table 9.

In2018, the mean COD concentration in the Bassac River (2.9 mg/L) was slightly higher than that of the Mekong River (2.47 mg/L9, which was slightly higher than the value recorded in 2017 (2.6 mg/L). This value is lower than the historical mean value of 2.7 mg/L from 1985 to 2017 (Table 11). The maximum COD concentration of 5.6 mg/L was recorded at Can Tho, Viet Nam in May 2018.

Figure 17 reveals that COD concentrations in the Mekong River increased slightly from 1985 to 2018. In contrast, the mean COD concentration for the 17 Mekong Stations was about 1.6 mg/L in 1985, while the mean COD concentration for the same stations was about 2.3 mg/L in 2017, and 2.47 mg/L in 2018.

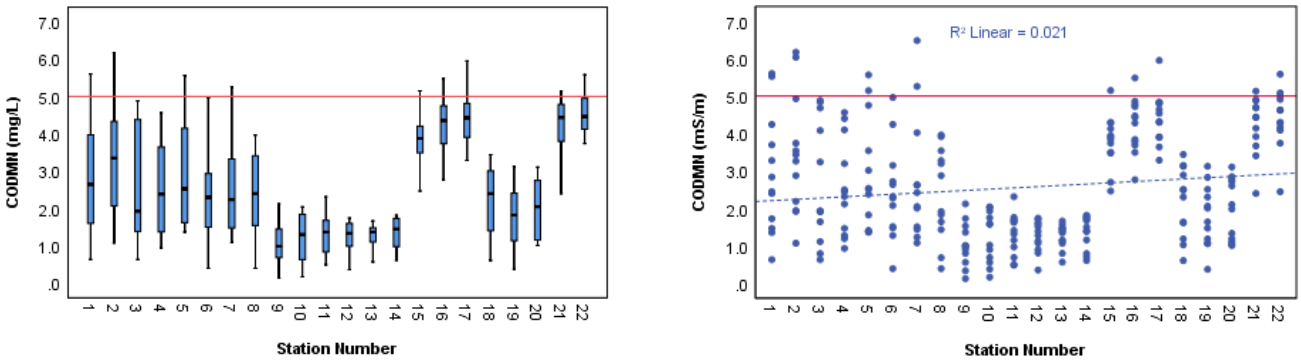


Figure 16. Spatial variation in COD (mg/L) at 22 stations along the Mekong (1–17) and Bassac (18–22) Rivers, 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

Note:

The horizontal lines at 5.0 represent COD target value of the WQGH.

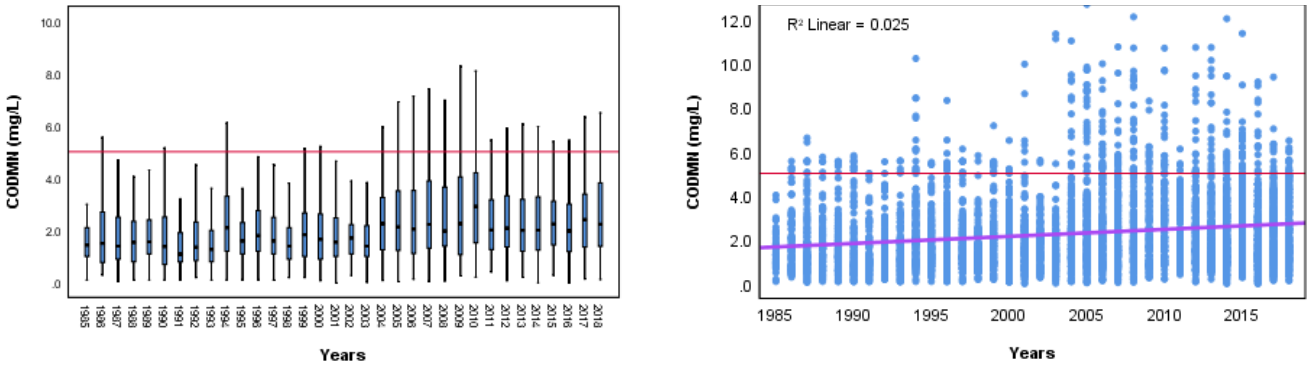


Figure 17. Temporal variation in COD (mg/L) in the Mekong River, from 2000 to 2018 and illustrated using box-and-whisker plot (left) and dot plot (right)

Note:

The horizontal lines at 5.0 represent COD target value of the WQGH.

3.2 Transboundary water quality

The MRC 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:

1. **China/Lao PDR** — A water quality monitoring station was established in Houa Khong in 2004 to monitor the boundary between the Upper and Lower Mekong Basin.
2. **Lao PDR/Myanmar** — There is no water quality station in this part of the river since it is remote and sparsely populated.
3. **Thailand/Lao PDR** — There are a number of monitoring stations along this stretch of the Mekong River, including those located in the vicinity of urban areas such as Vientiane, Nakhon Phanom and Savannakhet. However, none of the stations can be referred to as transboundary stations since they receive run-off from both countries and water is normally sampled in the middle of the river.
4. **Lao PDR/Cambodia** — While not located directly at the border of the two countries, Pakse and Stung Treng monitoring stations have, in the past, been considered as transboundary stations. Data from these stations have been used to assess transboundary effects on water quality.
5. **Cambodia/Viet Nam** — Both the Mekong and the Bassac Rivers have stations that can be used to capture transboundary effects on water quality. On the Mekong side, Kaorm Samnor station in Cambodia and Tan Chau in Viet Nam are located not too far from the Cambodian/Vietnamese border. Similarly, Koh Thom station in Cambodia and Chau Doc station in Viet Nam, which are located on the Bassac River, can be considered as transboundary stations, due to their proximity to the Cambodian/Vietnamese border.

3.2.1 Pakse vs. Stung Treng

A comparison of water quality at Pakse and Stung Treng Stations was carried out to examine potential transboundary water quality issues in the Mekong River between Lao PDR and Cambodia. For this purpose, six key parameters were selected based on the availability of data to support the assessment. These parameters are nitrate-nitrite, ammonium, TOTN, total phosphorus, DO and COD.

Figure 18 provides a summary of the comparison of 2018 water quality between the two stations. As can been seen in the figure, generally higher concentrations of ammonium were observed at Stung Treng than at Pakse. The average values of ammonium at Pakse and Stung Treng were M = 0.03 mg/L (Std. = 0.02) and M = 0.11 mg/L (Std. = 0.09). These conditions indicate that transboundary water quality issues associated with these parameters might be of potential concern. An independent t-test was carried out to determine whether the difference observed in mean concentrations of nitrate-nitrite, ammonium, and TOTN between the two stations was statistically significant. The results of an independent t-test reveal that the difference in mean concentrations of nitrate-nitrite, ammonium, and TOTN at Pakse was significant with a P-values of less than 0.01 for all three parameters. However, the average values of nitrate-nitrite and TOTN at Pakse were higher than those at Stung Treng. The average values of nitrate-nitrite at Pakse and Stung Treng were M = 0.51 mg/L (Std. = 0.19) and M = 0.17 mg/L (Std. = 0.08), and the average values of TOTN were 0.41 mg/l (Std.= 0.15) and 0.40 mg/l (Std.= 0.16). This indicates that there was likely no transboundary water quality issue of nitrogen between the two stations in 2018.

Similar to conditions observed for nitrate-nitrite, ammonium and TOTN, the P values for DO and COD at Parke and Stung Treng were less than 0.01. The values indicated that there was a significant difference between the means concentration of these parameters at the two stations. DO levels observed at the two stations further reveal that there is no potential issue with transboundary water quality, because the higher concentration was generally observed at Stung Treng, M=8.5 mg/L (Std. = 0.54), than at Pakse, 6.58 mg/L (Std. = 0.6).

Similarly, the average concentration of COD at Stung Treng was recorded at about 1.04 mg/L (Std. = 0.57) compared to 2.39 mg/L (Std. = 1.23) recorded at Pakse, which further indicated that there was likely no transboundary water quality issue between the two stations in 2018 regarding COD.

The average concentration of phosphorous at Stung Treng was recorded at about 0.08 mg/L (Std. = 0.08) compared to 0.07 mg/L (Std. = 0.02) recorded at Pakse. The average values were similar at the two stations, which was further confirmed by the P value of 0.59.

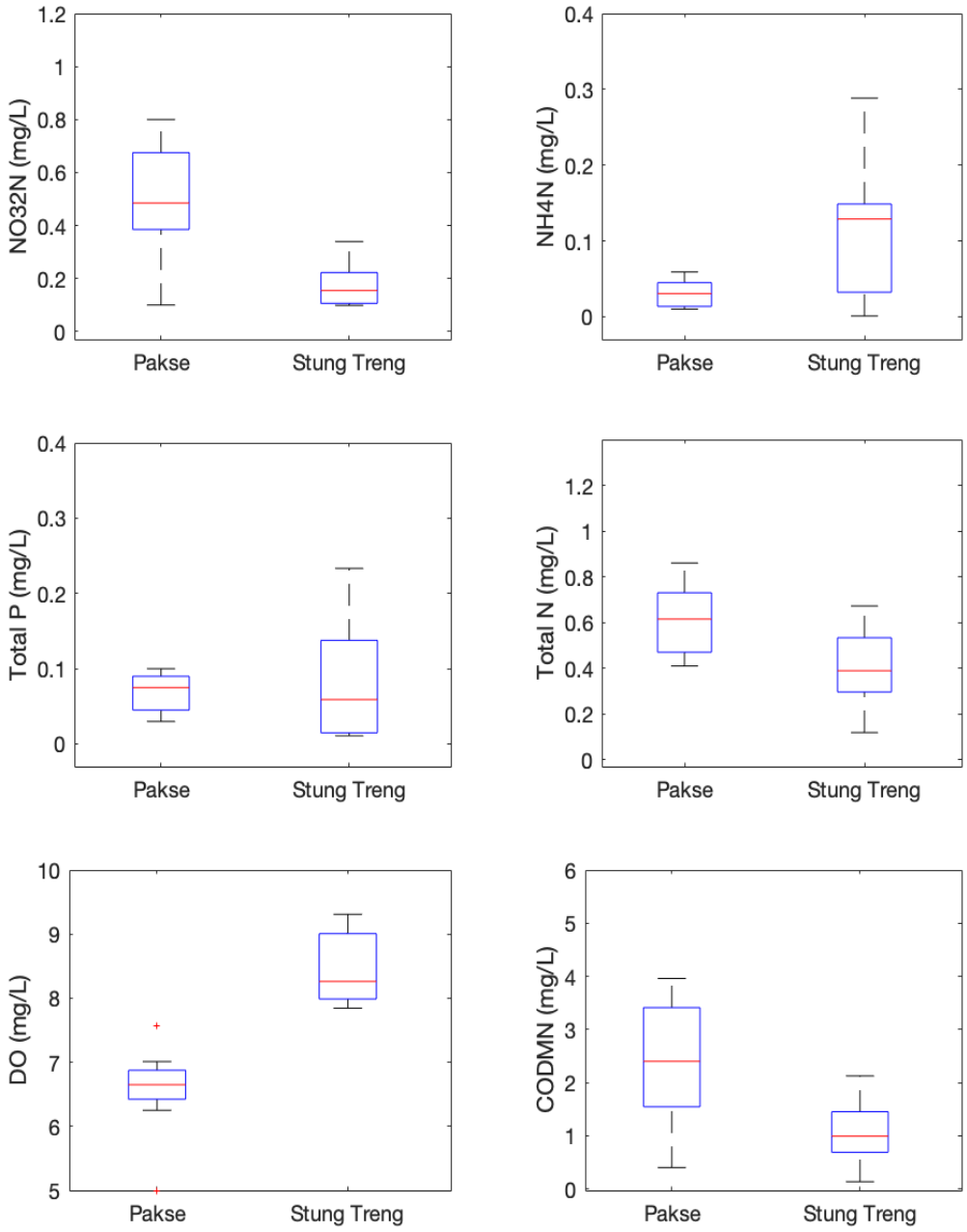


Figure 18. Comparisons of 2018 water quality data at Pakse and Stung Treng

3.2.2 Kaorm Samnor vs. Tan Chau

Kaorm Samnor and Tan Chau monitoring stations are located on the Mekong River, with Kaorm Samnor on the Cambodian side and Tan Chau on the Vietnamese side. To assess potential transboundary water quality issues at these two stations, a comparison was made

on a number of key water quality parameters, including nitrate-nitrite, ammonium, TOTN, total phosphorus, DO and COD. The outcomes of these analyses are illustrated in Figure 19.

In general, water quality in the Mekong River in 2018 was more degraded in Tan Chau than in Kaorm Samnor, with respect to the following parameters: nitrate-nitrite, TOTN, and COD. For instance, in 2018, generally higher levels of nitrate-nitrite, TOTN, and COD were observed at Tan Chau than at Kaorm Samnor. Statistically, Independent t-tests revealed that there were significant differences in levels of NO_{32}, TOTN, and COD at these two stations with the P values of less than 0.01. Concentrations of these parameters were higher in the downstream station than in the upstream one, which indicates the possibility of a transboundary water quality issue. However, maximum concentrations did not exceed those of the WQGH and the WQGA in 2018.

With DO appearing to be negatively correlated to NO_{32}, TOTN, and COD (Table 9), the levels of DO at these two stations were directly opposite those of NO32, TOTN, and COD – higher in Kaorm Samnor (Figure 19). The mean concentrations of DO were M = 6.8 mg/L (Std = 0.4) at Kaorm Samnor and M = 5.4 mg/L (Std = 0.4) at Tan Chau with the P value of less than 0.01.

In contrast, an independent t-test showed that there was no significant difference between the mean concentrations of ammonium (P value of 0.14) and total phosphorus (P value of 0.5) concentrations. The mean concentrations of ammonium were M = 0.1 mg/ (Std = 0.1) at Kaorm Samnor and M = 0.1 mg/L (Std = 0.0) at Tan Chau. Similarly, the mean concentrations of Total Phosphorous were M = 0.1 mg/L (Std = 0.1) at Kaorm Samnor and M = 0.1 mg/L (Std = 0.1) at Tan Chau.

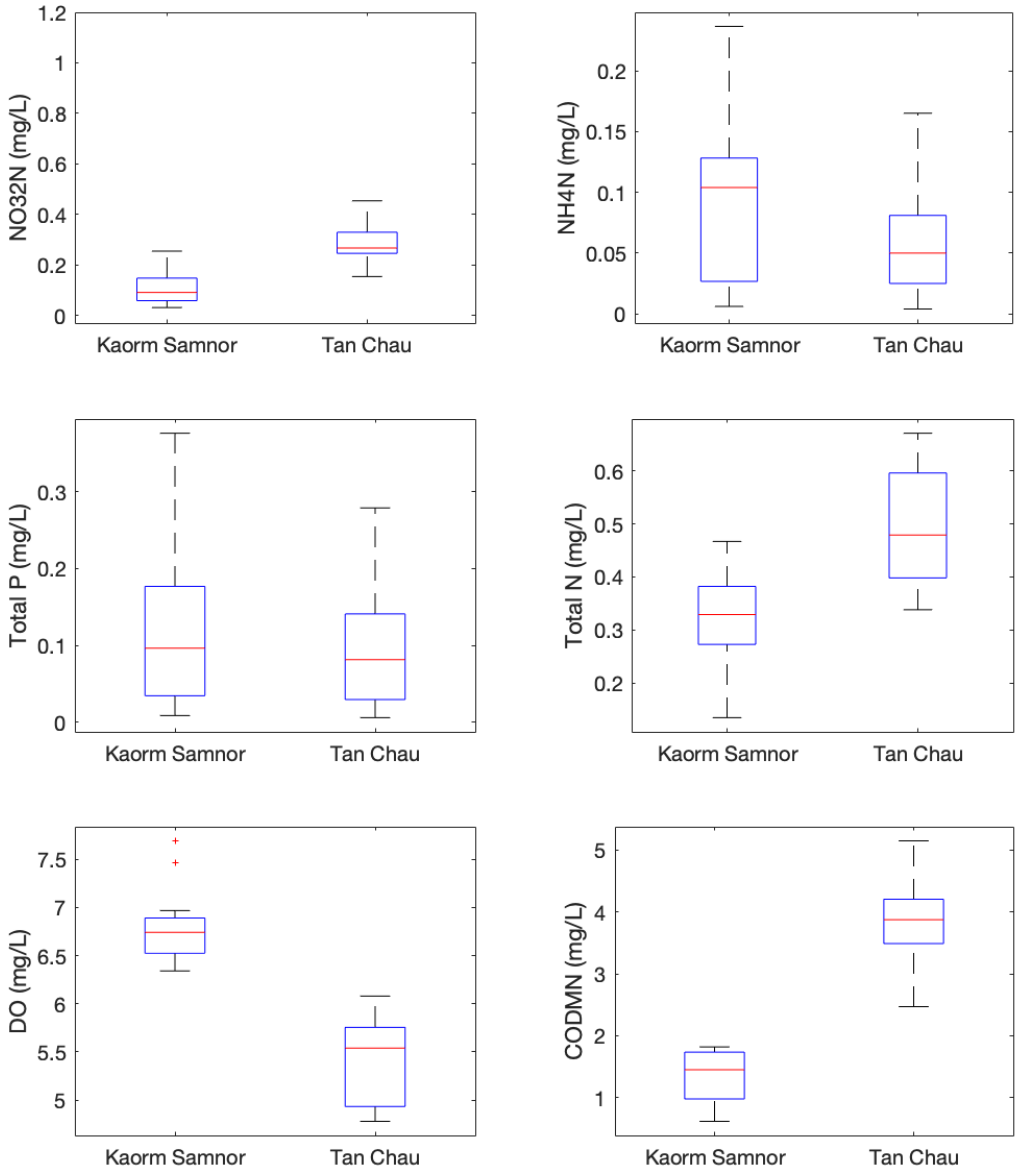


Figure 19. Comparisons of water quality data at Kaorm Samnor and Tan Chau

3.2.3 Koh Thom vs. Chau Doc

Similar analysis was carried out for Koh Thom (on the Cambodian side of the river) and Chau Doc (on the Vietnamese side of the river) water quality monitoring stations on the Bassac River to assess potential transboundary water quality issues. Figure 20 illustrates comparisons of the concentrations of nitrate-nitrite, ammonium, TOTN, total phosphorus, DO and COD recorded at Koh Thom and Chau Doc monitoring stations in 2018.

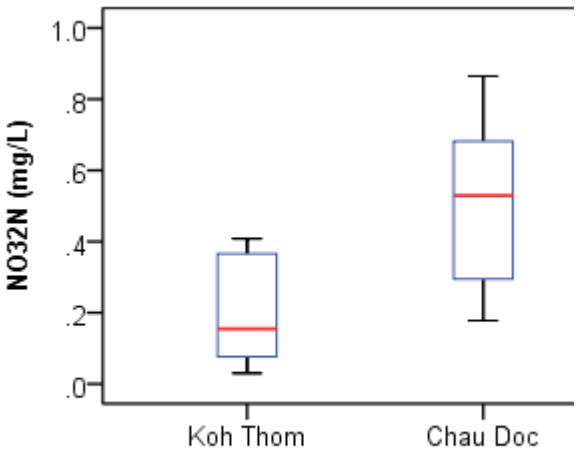
In terms of pollutant levels, Figure 20 shows that, in 2018, concentrations of NO_{32}, TOTN, and COD were generally higher in the downstream station (Chau Doc) than the upstream station (Koh Thom). This is similar to conditions detected between Kaorm Samnor and Tan Chau (Section 3.2.2) and may reflect pollution discharges between the two stations in relation to these parameters.

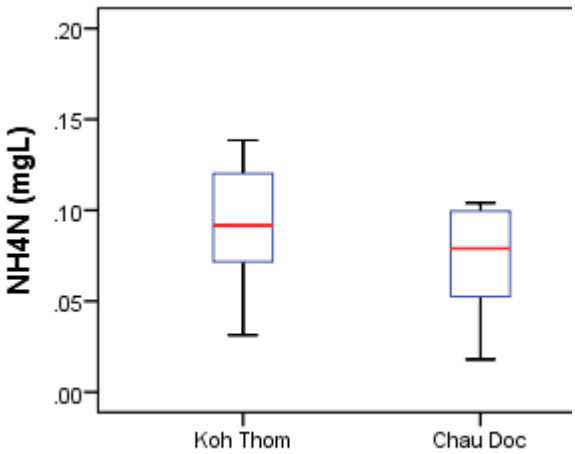
The analysis of individual parameters in 2018 for both stations revealed that the observed difference in the mean concentrations of NO_{32}, TOTN, COD, and DO were statistically significant, with a P value of less than 0.01. Mean nitrate-nitrite concentrations for Koh Thom and Chau Doc were estimated at 0.2 mg/L (Std = 0.1) and 0.5 mg/L (Std = 0.2), respectively. However, with the maximum concentrations recorded at less than 1 mg/L for both stations, NO_{32} levels at these stations were still well below the recommended WQGH and the WQGA (5 mg/L).

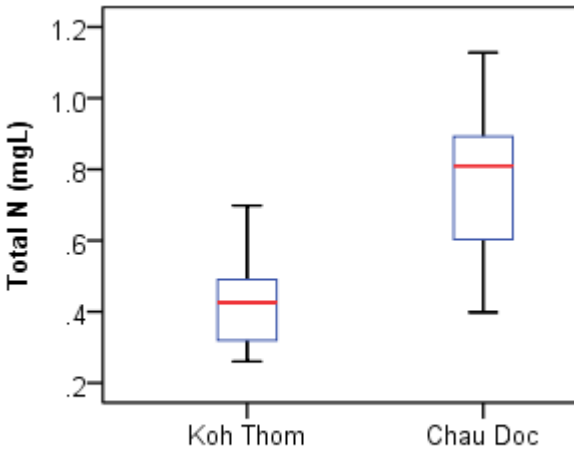
In the case of TOTN, the result of an independent t-test for both stations revealed that the difference in the mean concentrations of TOTN was statistically significant, with a P value of about 0. Mean TOTN concentrations for Koh Thom and Chau Doc were estimated at 0.4 mg/L (Std = 0.11) and 0.8 mg/L (Std = 0.2), respectively.

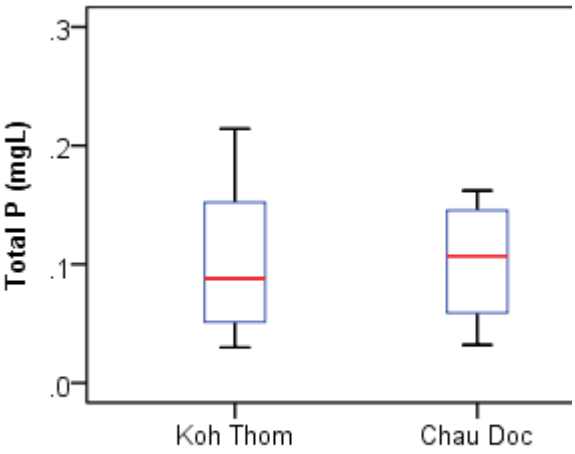
The observed difference in the mean concentrations of COD, between Koh Thom (M = 2.0 mg/L, Std = 0.8) and Chau Doc (M = 4.2 mg/L, Std = 0.8), was statistically significant, with a P value of less than 0.01. However, the maximum COD concentrations at the two stations were still below the MRC WQGH (5 mg/L), indicating that there is no transboundary issue.

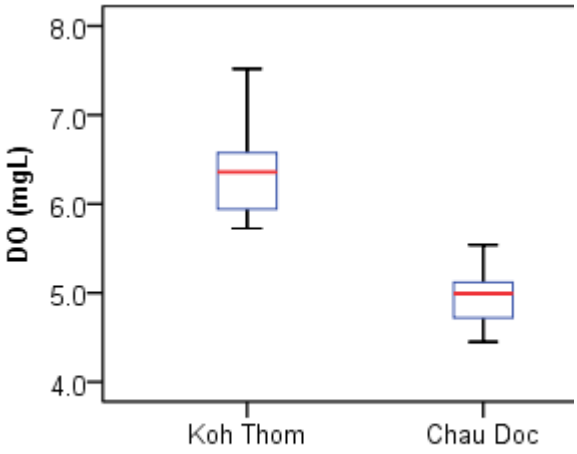
DO concentrations at Chau Doc were recorded to be generally lower than those recorded at Koh Thom. A comparison of mean DO concentrations between the two stations revealed that the difference was statistically significant, with a P value of less than 0.01. Mean DO concentrations for Koh Thom and Chau Doc were estimated at 6.3 mg/L (Std = 0.7) and 5 mg/L (Std = 0.4), respectively. With 100% of DO values monitored in Chau Doc being lower than 6 mg/L (WQGH), there is a potential concern with regard to the human use of river at the station. It should be noted, however, that although all values exceeded the WQGH (6 mg/L), none violated the WQGA, indicating that the water quality at the station was still suitable for aquatic life, but should be closely monitored to ensure the detection of potential future violation of the WQGA.

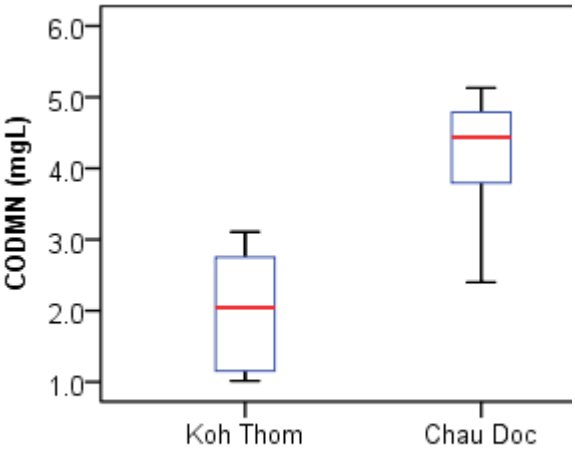

NO32N (mg/L)
1.0
.8
.6
.4
.2
.0
Koh Thom
Chau Doc


NH4N (mgL)
.20
.15
.10
.05
.00
Koh Thom
Chau Doc


Total N (mgL)
1.2
1.0
.8
.6
.4
.2
Koh Thom
Chau Doc


Total P (mgL)
.3
.2
.1
.0
Koh Thom
Chau Doc


DO (mgL)
8.0
7.0
6.0
5.0
4.0
Koh Thom
Chau Doc


CODMN (mgL)
6.0
5.0
4.0
3.0
2.0
1.0
Koh Thom
Chau Doc

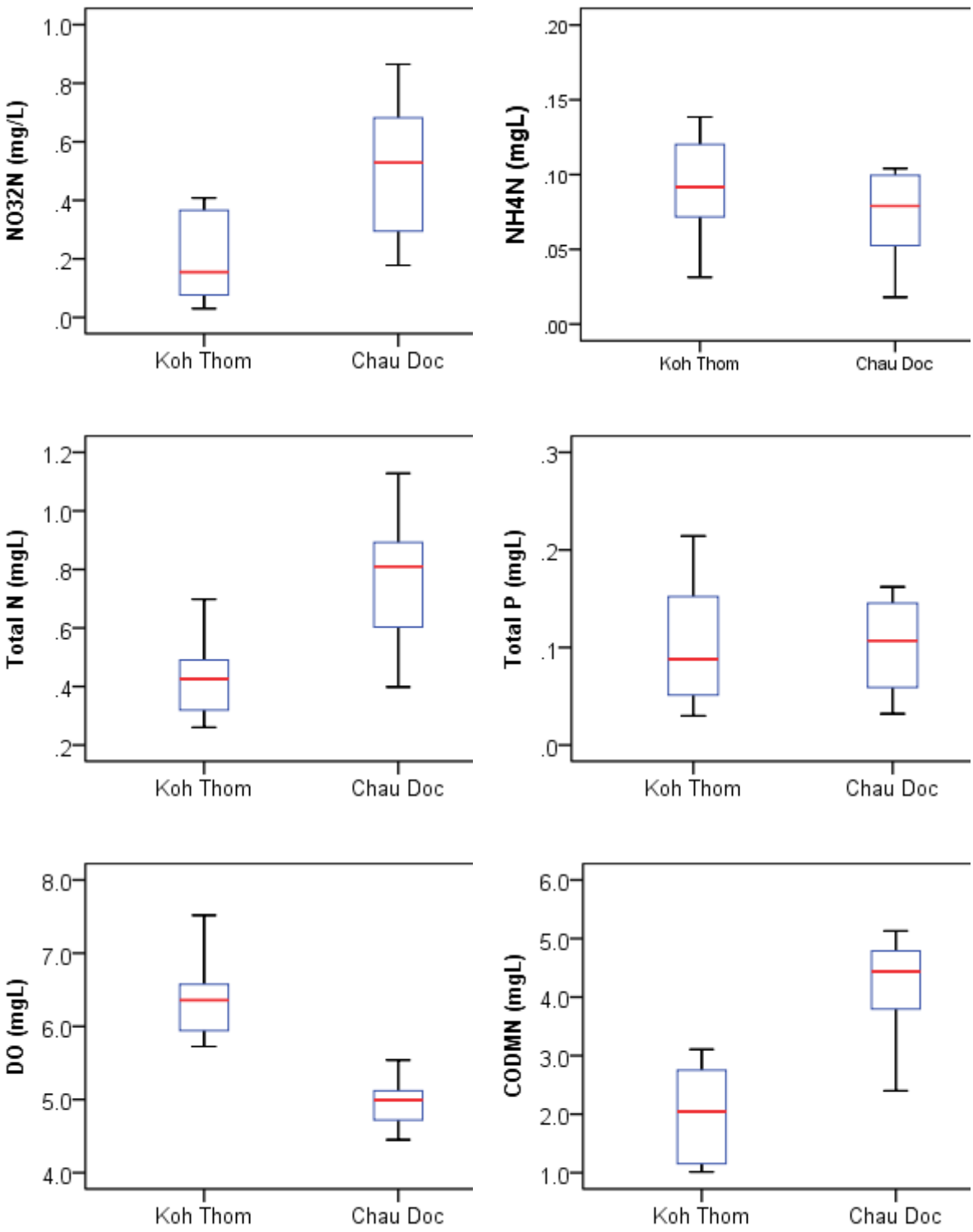


Figure 20. Comparisons of water quality data at Koh Thom and Chau Doc

3.3 The water quality indices

3.3.1 The Water Quality Index for the Protection of Aquatic Life

In 2018, water quality of the Mekong and Bassac Rivers was classified in a range from 'moderate' to 'excellent' for the protection of aquatic life (**Table 12**). In 2018, four stations were classified as 'excellent' for the protection of aquatic life, including Luang Prabang, Vientiane, Khong Chiam and Stung Treng. In contrast, water quality in one station was recorded as only 'moderate' for the protection of aquatic life (Chau Doc). The remaining stations were classified as 'good' for the protection of aquatic life.

Compared to 2017, the water quality of Mekong and Bassac Rivers was classified as less suitable for aquatic life, with only three stations (Luang Prabang, Vientiane, Khong Chiam, and Stung Treng) rated as 'excellent'. In comparison, nine stations were recorded as 'excellent' in 2017. Overall, water quality at eight stations was worse in 2018 than in 2017: according to the WQGA, the classification of water quality in seven stations decreased from 'excellent' to 'good' (Savannakhet, Pakse, Kampong Cham, Chrouy Changvar, Neak Loung, Kaorm Samnor and Tan Chau) and one station from 'good' to 'moderate' (Chau Doc). This was due to the elevated levels in total COD, NO_{32}, and NH_4, and the reduction in DO concentrations.

In contrast, 2018 saw water quality improvement at two stations where the rating according to the WQGA improved from 'good' to 'excellent'. These two stations were Luang Prabang and Khong Chiam. The improvement was due to the improved levels of DO and reduced instream concentration levels of NO_{32} compared to levels recorded in 2017.

Table 12. Rating of water quality of the Mekong River (from 1 to 17) and the Bassac River (from 18 to 22) according to the WQGA, 2008–2018

No.	Station Names	Countries	Class										
			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	Houa Khong	Lao PDR	A*	A	A	A	B	B	B	B	B	B	B
2	Chiang Saen	Thailand	A	B	B	A	B	B	A	B	B	B	B
3	Luang Prabang	Lao PDR	A	A	B	A	A	B	B	B	A	B	A
4	Vientiane	Lao PDR	A	A	A	A	A	B	B	A	A	A	A
5	Nakhon Phanom	Thailand	B	A	B	A	B	B	A	A	B	B	B
6	Savannakhet	Lao PDR	A	A	A	A	A	B	B	B	A	A	B
7	Khong Chiam	Thailand	B	A	A	A	A	B	A	A	A	B	A
8	Pakse	Lao PDR	A	A	A	A	A	B	B	B	A	A	B
9	Stung Trieng	Cambodia	B	B	B	B	B	B	B	B	B	A	A
10	Kratie	Cambodia	B	B	B	B	B	B	B	B	A	B	B
11	Kampong Cham	Cambodia	B	B	B	B	B	B	A	B	A	A	B
12	Chrouy Changvar	Cambodia	B	B	B	B	B	B	B	B	A	A	B
13	Neak Loung	Cambodia	B	B	B	B	B	B	B	B	A	A	B
14	Kaorm Samnor	Cambodia	B	B	B	B	B	B	B	B	A	A	B
15	Tan Chau	Viet Nam	B	B	B	B	B	B	B	B	B	A	B
16	My Thuan	Viet Nam	B	B	B	B	B	B	B	B	B	B	B

17	My Tho	Viet Nam	C	C	C	C	B	C	C	C	D	C	B
18	Takhmao	Cambodia	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
20	Koh Thom	Cambodia	B	B	B	B	B	B	A	B	B	B	B
21	Chau Doc	Viet Nam	B	B	B	B	B	B	B	B	B	B	C
22	Can Tho	Viet Nam	B	C	C	C	C	C	B	B	B	B	B

Note:

*A: High; B: Good; C: Moderate; D: Poor; E: Very Poor.

3.3.2 Water Quality Index for the Protection of Human Health

Analysis of the 2018 water quality data, using the Water Quality Index for Human Health, reveals that water quality of the Mekong and Bassac Rivers for the protection of human health is still of good quality, with all stations rated as either 'good' or 'excellent' (**Table 13**).

in 2018, 11 of the 22 stations located in the Mekong and Bassac Rivers were classified as 'excellent' for the protection of human health while the other 11 were classified as 'good'. Among the 11 stations classified as 'excellent', six stations were located in Cambodia. With the three Bassac River's monitoring stations (Koh Khel and Koh Thom) also classified as 'excellent', all stations monitored by the Cambodian WQMN laboratory in 2018 were classified as 'excellent' in 2018. Since 2009, these stations have been consistently rated as 'excellent' for human health acceptability.

Historically, water quality of the Mekong and Bassac Rivers has been acceptable for human health with a classification of mostly 'good' or 'excellent'. The only exceptions were recorded in 2009 (Tan Chau, My Tho and Chau Doc), 2010 (My Thuan, My Tho, Chau Doc, and Can Tho) and 2014 (Houa Khong, Savannakhet, and Takhmao) where a few stations were classified as "moderate". Despite the overall 'good' to 'excellent' quality, water quality of the Mekong and Bassac Rivers slightly degraded in 2018 compared to in 2017, with five stations recorded lower rating scores compared to the previous years (Table 13). These stations were Houa Khong, Luang Prabang, Tan Chau, Takhmao and Can Tho.

Table 13. Rating of water quality of the Mekong River (from 1 to 17) and the Bassac River (from 18 to 22) for the protection of human health, 2008–2018

No.	Station Names	Countries	Class										
			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	Houa Khong	Lao PDR	A*	A	B	A	B	B	C	A	A	A	B
2	Chiang Saen	Thailand	B	B	B	A	B	B	B	B	B	B	B
3	Luang Prabang	Lao PDR	A	A	B	A	B	A	B	B	B	A	B
4	Vientiane	Lao PDR	A	A	B	A	B	B	B	B	B	A	A
5	Nakhon Phanom	Thailand	B	B	B	B	B	B	B	B	B	B	B
6	Savannakhet	Lao PDR	A	A	A	A	B	B	C	B	B	A	A
7	Khong Chiam	Thailand	B	B	B	A	B	B	B	B	B	B	B
8	Pakse	Lao PDR	B	A	A	A	A	B	A	B	B	A	A

9	Stung Trieng	Cambodia	B	A	A	A	A	A	A	A	A	A	A
10	Kratie	Cambodia	B	A	A	A	A	A	A	A	A	A	A
11	Kampong Cham	Cambodia	B	A	A	A	A	A	A	B	A	A	A
12	Chrouy Changvar	Cambodia	B	A	A	A	A	A	A	A	A	A	A
13	Neak Loung	Cambodia	B	A	A	A	A	A	A	B	A	A	A
14	Kaorm Samnor	Cambodia	B	A	A	A	B	A	A	B	A	A	A
15	Tan Chau	Viet Nam	B	C	B	B	A	A	A	A	A	A	B
16	My Thuan	Viet Nam	B	B	C	A	A	B	A	A	A	B	B
17	My Tho	Viet Nam	B	C	C	B	B	B	B	A	B	B	B
18	Takhmao	Cambodia	B	A	A	A	A	B	C	A	B	A	B
19	Koh Khel	Cambodia	A	A	B	A	B	B	A	B	A	A	A
20	Koh Thom	Cambodia	B	A	A	A	B	B	A	A	A	A	A
21	Chau Doc	Viet Nam	B	C	C	B	B	A	A	A	A	B	B
22	Can Tho	Viet Nam	B	B	C	B	A	A	A	A	A	A	B

Note:

*A: Excellent; B: Good; C: Moderate; D: Poor; E: Very Poor

3.3.3 Water quality indices for agricultural use

The level of degradation 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 degradation of water quality for general irrigation and paddy rice irrigation, all indices for agricultural use can be assessed against threshold values for EC (**Table 8**).

An analysis of C reveals that all EC values fell within the guideline value of 70 mS/m for the Water Quality Index for General Irrigation Use. With no recorded value greater than 70 mS/m, it can be concluded that there was no restriction for all types of agricultural use of Mekong and Bassac River water in the upper part of the river. However, when using water for agriculture in the Delta of Viet Nam, it is necessary to thoroughly examine the water quality. The level of impairment of the Mekong and Bassac Rivers' water quality for agricultural use is summarised in **Table 14**. The WQI_{ag} has been relatively stable in the last 10 years, with water quality from all the stations classified as 'A', which implies no restrictions for general irrigation and paddy rice.

Table 14. Rating of water quality of the Mekong River (from 1 to 17) and the Bassac River (from 18 to 22) for agricultural use, 2008–2018

No.	Station Names	Countries	Class										
			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	Houa Khong	Lao PDR	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
3	Luang Prabang	Lao PDR	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
5	Nakhon Phanom	Thailand	A	A	A	A	A	A	A	A	A	A	A

No.	Station Names	Countries	Class										
			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
6	Savannakhet	Lao PDR	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
8	Pakse	Lao PDR	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
10	Kratie	Cambodia	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
12	Chrouy Changvar	Cambodia	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
14	Kaorm Samnor	Cambodia	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
16	My Thuan	Viet Nam	A	A	A	A	A	A	A	A	A	A	A
17	My Tho	Viet Nam	A	A	A	A	A	A	A	A	B	A	A
18	Takhmao	Cambodia	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
20	Koh Thom	Cambodia	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
22	Can Tho	Viet Nam	A	A	A	A	A	A	A	A	A	A	A

Note:

*A: No restriction; B: Some restriction; C: Severe restriction

Conclusions and recommendations

4.1 Conclusions

This report provides an overall assessment of water quality of the Mekong and Bassac River in 2018, using 19 water quality parameters recommended in the MRC TGPWQ as proxies for water quality. The analyses of water quality data collected from 17 Mekong River and 5 Bassac River monitoring stations revealed that water at these stations was of good quality in 2018, with only a small number of COD and DO measurements that did not comply with the WQGH and the WQGA (Tables 10 and 11).

Most the exceedances were recorded in the Delta. Of a slight concern is the DO levels at Chau Doc, which were not in compliance with the WQGH for all sampling occasions, causing the rating of Water Quality Index for the Protection of Aquatic Life to be downgraded from 'good' in 2017 to 'moderate' in 2018. Prior to 2018, water quality at Chau Doc was consistently rated 'good' for the protection of aquatic life. The Pearson's correlation analysis revealed that the reduction in DO levels was related to the elevated levels in COD and NO_{32}. Increased levels of COD and NO_{32} have been known to increase the amount of instream oxidizable organic materials that consume oxygen during breakdown processes (Woodard and Curran, 2006). Outside of the 'moderate' classification recorded at Chau Doc, water quality of the Mekong and Bassac Rivers for the protection of aquatic life was either 'good' or 'excellent' with four stations classified as 'excellent'. However, when compared to 2017, a combination of reducing DO levels and increasing COD, NO_{32}, and NH_4 levels appeared to have affected the classification of the Water Quality Index for the Protection of Aquatic Life at seven stations, which lowered from 'excellent' in 2017 to 'good' in 2018.

Despite the increased levels of impairment to the aquatic life, water quality of the Mekong and Bassac River continued to be either 'good' or 'excellent' for human health with 50% rated as 'good' and the remaining rated as 'excellent'. It should be noted that the water quality at all Mekong and Bassac River stations within Cambodia was rated 'excellent' in 2018 for the protection of human health.

With the exception of the non-compliance recorded in DO and COD levels, EC levels were recorded to be well below the lowest allowable limit of the MRC Water Quality Guidelines for the Protection of Human Health and Aquatic Life (70-150 mS/m). However, it should be noted that the Mekong River is generally characterized as a low saline river with the average EC rarely exceeding 40 mS/m and historical average of 20.7 when sampling during low tide (Section 3.1.2). With no recorded noncompliance with the guideline values for Water Quality Indices for General Irrigation and Paddy Rice Irrigation, it can be concluded that there were no restriction for any type of agricultural use of the Mekong and Bassac Rivers water. It should be noted, however, that water quality monitoring in the Mekong Delta was undertaken during low tide, and therefore, suitability of water for agricultural use may differ during the high tide.

Compared to the 2017 data, water quality of the Mekong and Bassac River did not change significantly in 2018. However, historical comparisons (1985 to 2018) suggest that water quality changed significantly for many parameters including TSS, which showed a reduction of yearly mean concentration from 388 mg/L in 1985, to 84.9 mg/L in 2018, i.e. about a 78% reduction. Concentrations of NO_{32}, NH_4, COD and DO also changed during the same period, with DO levels reduced from 7 mg/L in 1985, to 6.9 mg/L in 2018, while COD level increased from 1.6 to 2.47 mg/L.

In terms of transboundary river pollution, while analyses of water quality data at Pakse/Stung Treng, Kaorm Samnor/Tan Chau, and Koh Thom/Chau Doc reveal significant differences of levels of NO_{32}, TOTN, and COD at these stations, with P values of less than 0.01, the levels were still well below the WQGH and the WQGA. However, the combined levels of these pollutants appear to have affected DO levels, in particular at Chau Doc, and should continue to be closely monitored to ensure that any further change that may have potential effects on human health and aquatic life are detected in a timely manner and remedial action is taken.

4.2 Recommendations

The MRC MCs' efforts to maintain acceptable/good water quality of the Mekong and Bassac Rivers requires that compliance with the Procedure for Water Quality and its associated Technical Guidelines (TGWQ) are closely monitored. The TGWQ provides a number of additional water quality indicators for monitoring in the near future. These indicators have been added taking into account emerging threats to water quality, including population growth, intensive agriculture and aquaculture, navigation, hydropower and industrialisation, which can often lead to increased inputs of chemicals and debris that can ultimately affect the aquatic ecosystems and human health.

While specific monitoring programmes have been carried out to complement activities of the WQMN, including the Joint Environmental Monitoring and the Multi-Media Monitoring and Assessment of the Mekong Riverine, considering the current status of water quality as highlighted in the report and a potential increase in development and population growth, the following are recommended for the sustainable implementation of the routine water quality monitoring under the MRC WQMN:

- Closely monitor the DO levels in the mainstream stations including those highlighted in this report as being of concern in order to ensure that any further change that may have potential effects on human health and aquatic life are detected in a timely manner and remedial action is taken.
- Explore the feasibility and potential short- and long-term monitoring benefits of riverine micro and macro plastic monitoring taking into consideration the status of these pollutants and their current and future risks to the aquatic ecosystems and human health.
- Improve and update the water quality monitoring knowledge and skills for national laboratories by providing the training programmes.

- Find the solutions to improve the sampling processes, especially in remote areas (e.g. close to the Lao PDR-Myanmar border and possibly the Lao PDR-China border).
- Explore the feasibility for monitoring additional water quality parameters listed in Chapters 1 and 2 of the TGWQ including heavy metals and persistent and non-persistent organic substances.
- Further apply and expand JEM programme to install automatic monitoring stations at some selected stations especially at 200–500 m downstream of each Mekong mainstream dams to have timely, high frequency delivery of information on water quality.
- Continue to conduct proficiency tests at laboratories with support from the MRCS.
- Assist national designated laboratories in achieving ISO/IEC 17025 certificates, which will certify that they operate competently and generate valid results. This would promote confidence in the monitoring results nationally, regionally and globally.

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Annexes: Trends of Key Water Quality Parameters in the Tributaries of the Mekong River

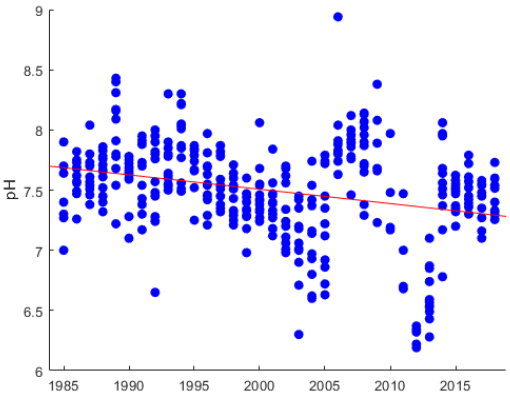
Annexe 1.1 Chiang Rai (Thailand)

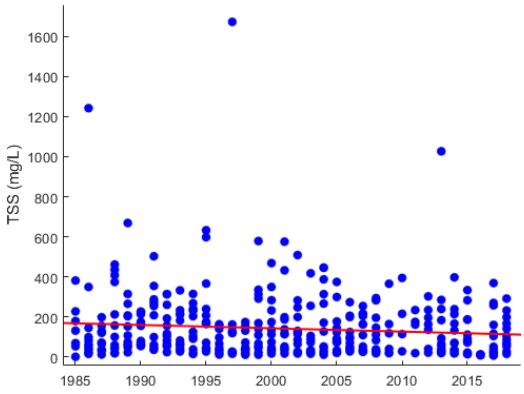
Table A.1. Trends of key water quality parameters at Chiang Rai Water Quality Station

Parameters	Unit	Kendall tau values	p-values
pH	-	-0.18	2.0234e-07
TSS	mg/L	-0.082	0.017911
EC	mS/m	0.141	5.1017e-05
NO_{3-2} -N	mg/L	0.00775	0.8261
NH_4-N	mg/L	0.0763	0.034179
TOTP	mg/L	0.371	2.22e-16
DO	mg/L	0.00835	0.81457
CODMN	mg/L	0.327	2.22e-16

Note:

p-value < 0.05 indicates significant change, negative (-) Kendall tau value indicates decreasing trend, and positive (+) Kendall tau value indicates increasing trend.





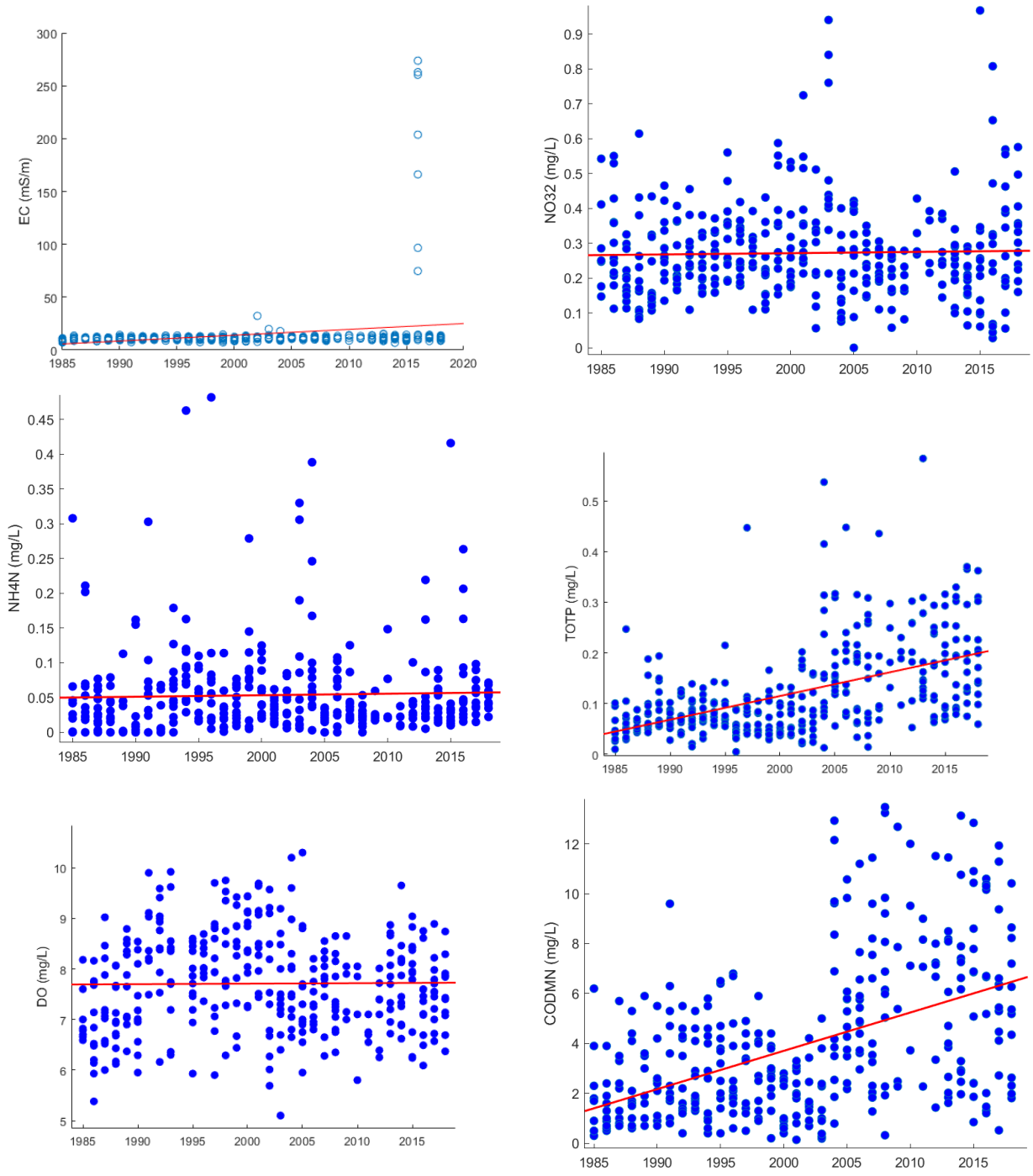


Figure A.1. Temporal trends of key water quality parameters at Chiag Rai Water Quality Monitoring Station

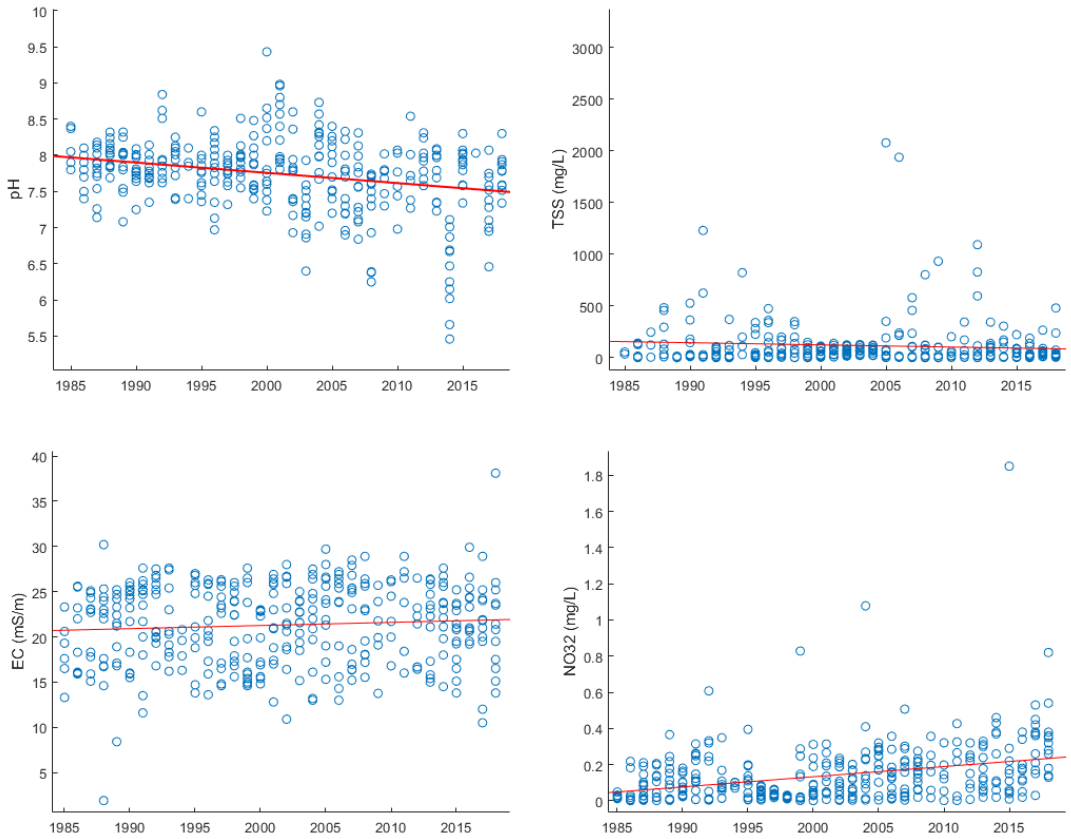
Annexe 1.2 Ban Hatkham (Lao PDR)

Table A.2. Trends of key water quality parameters at Ban Hatkham Water Quality Station

Parameters	Unit	Kendall tau values	p-values
pH	-	-0.153	1.5401e-05
TSS	mg/L	-0.0169	0.64748
EC	mS/m	0.032	0.36285
NO_{3-2}-N	mg/L	0.245	7.2509e-12
NH_4-N	mg/L	-0.0208	0.58004
TOTP	mg/L	0.151	4.0496e-05
DO	mg/L	-0.33	2.22e-16
CODMN	mg/L	0.25	0.00214

Note:

p-value < 0.05 indicates significant change, negative (-) Kendall tau value indicates decreasing trend, and positive (+) Kendall tau value indicates increasing trend.



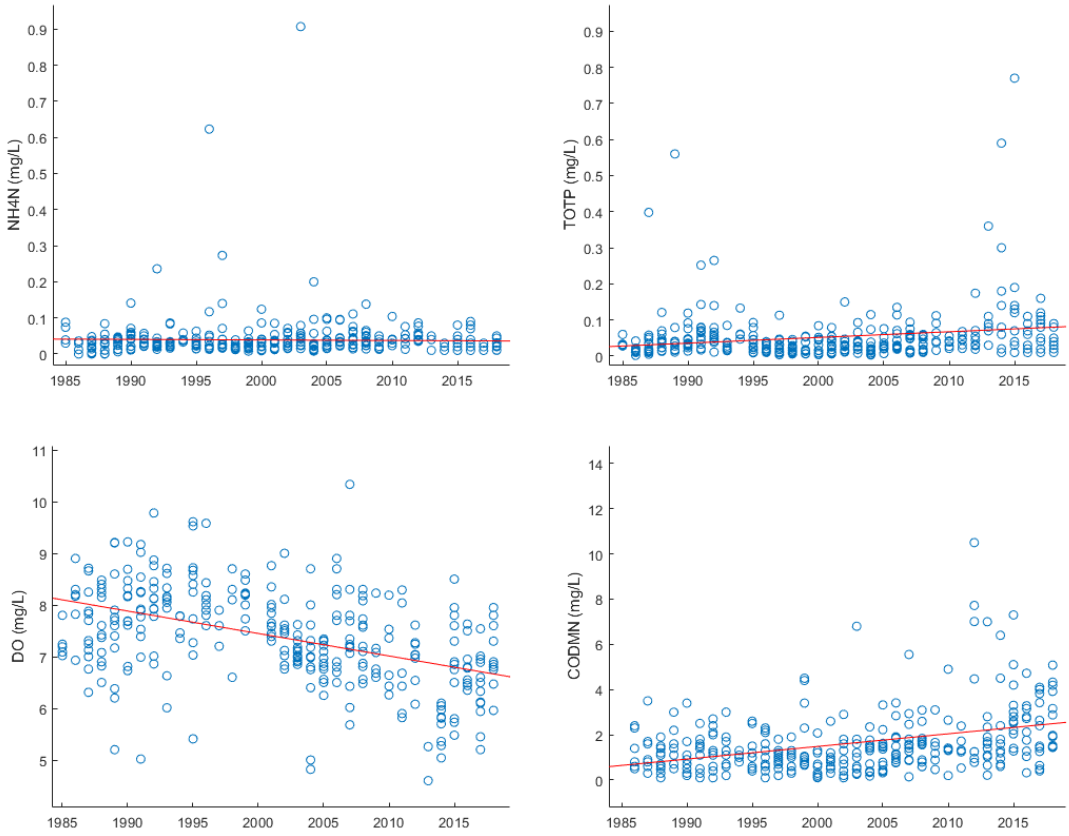


Figure A.2. Temporal trends of key water quality parameters at Ban Hatkham Water Quality Monitoring Station

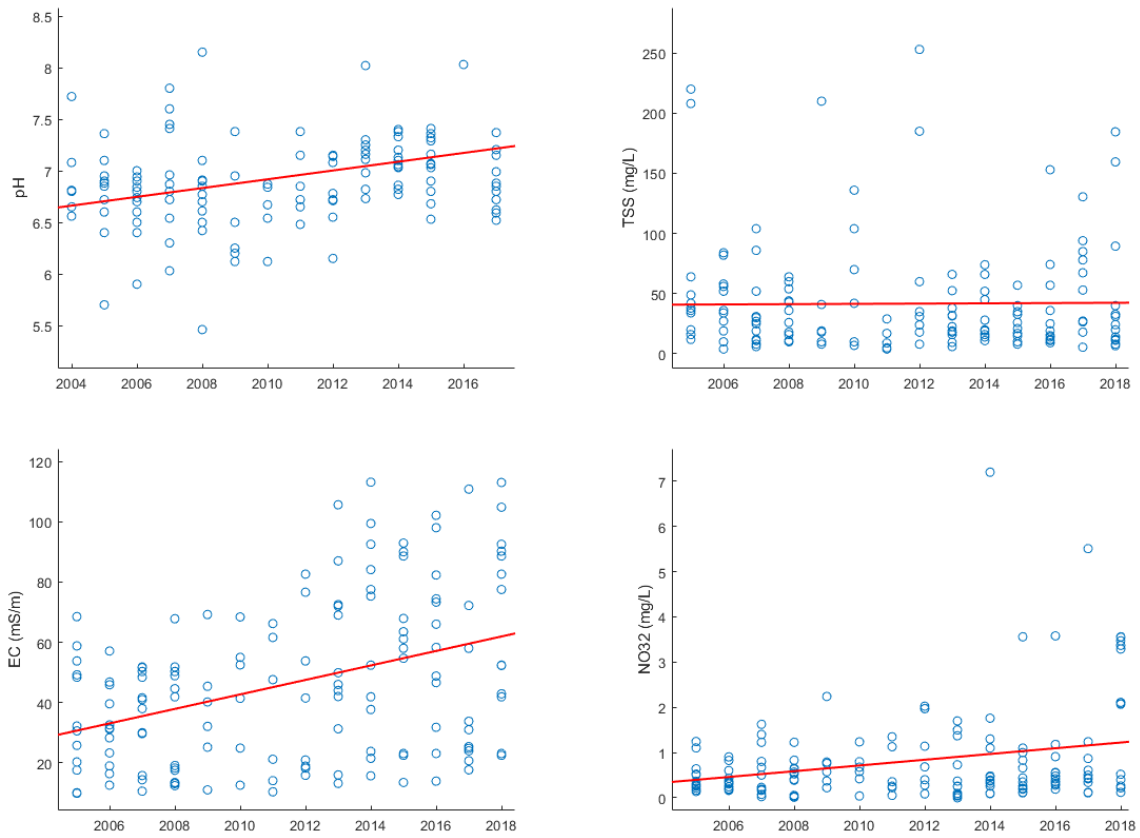
Annexe 1.3 Houay Mark Hiao (Lao PDR)

Table A.3 Trends of key water quality parameters at Houay Mark Hiao Water Quality Station

Parameters	Unit	Kendall tau values	p-values
pH	-	0.242	1.261e-05
TSS	mg/L	-0.00258	0.96278
EC	mS/m	0.235	1.8356e-05
NO_{3-2}-N	mg/L	0.121	0.026998
NH_4-N	mg/L	-0.233	22.7509e-05
TOTP	mg/L	0.045	0.42261
DO	mg/L	0.196	0.00037484
CODMN	mg/L	-0.152	0.0054064

Note:

p-value < 0.05 indicates significant change, negative (-) Kendall tau value indicates decreasing trend, and positive (+) Kendall tau value indicates increasing trend.



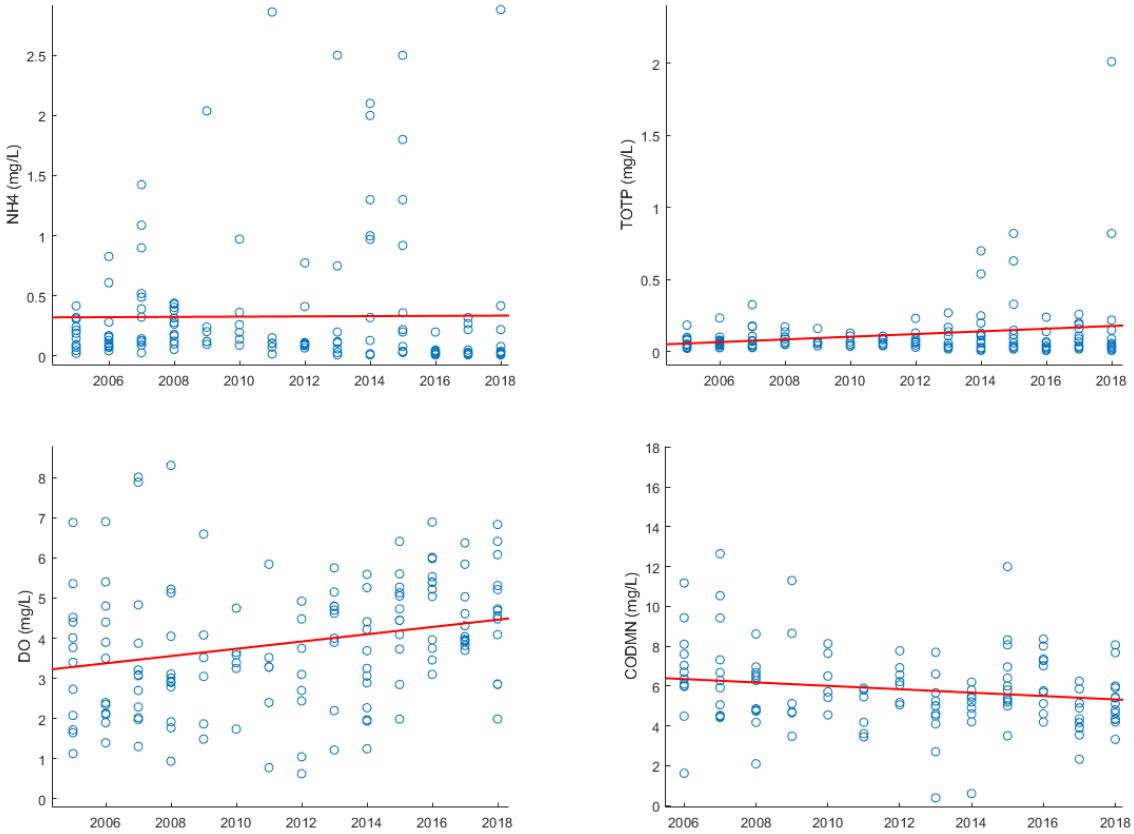


Figure A.3. Temporal trends of key water quality parameters at Houay Mak Hiao Water Quality Monitoring Station

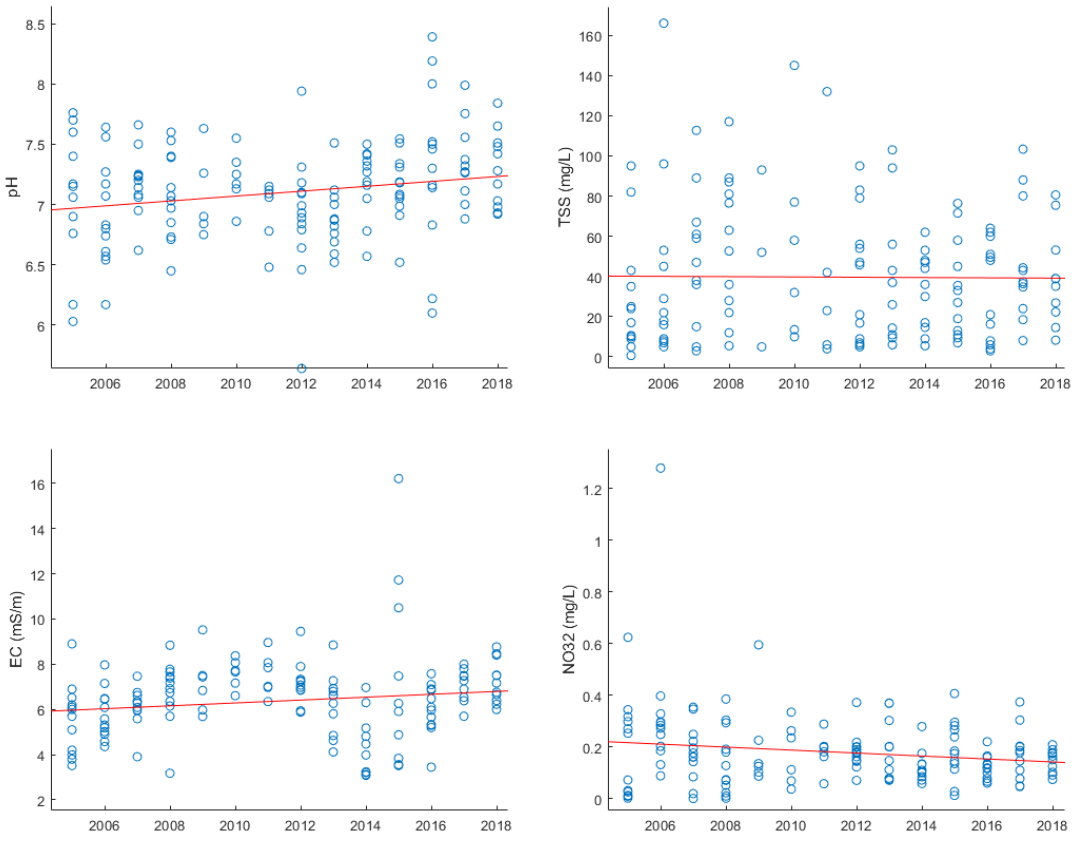
Annex 1.4 Lumphat (Cambodia)

Table A.4. Trends of key water quality parameters at Lumphat Water Quality Station

Parameters	Unit	Kendall tau values	p-values
pH	-	0.126	0.021498
TSS	mg/L	0.0513	0.35454
EC	mS/m	0.115	0.035049
NO_{3-2}-N	mg/L	-0.0527	0.34188
NH_4-N	mg/L	0.136	0.017019
TOTP	mg/L	0.0617	0.26939
DO	mg/L	-0.0252	0.64962
CODMN	mg/L	-0.265	1.7267e-06

Note:

p-value < 0.05 indicates significant change, negative (-) Kendall tau value indicates decreasing trend, and positive (+) Kendall tau value indicates increasing trend.



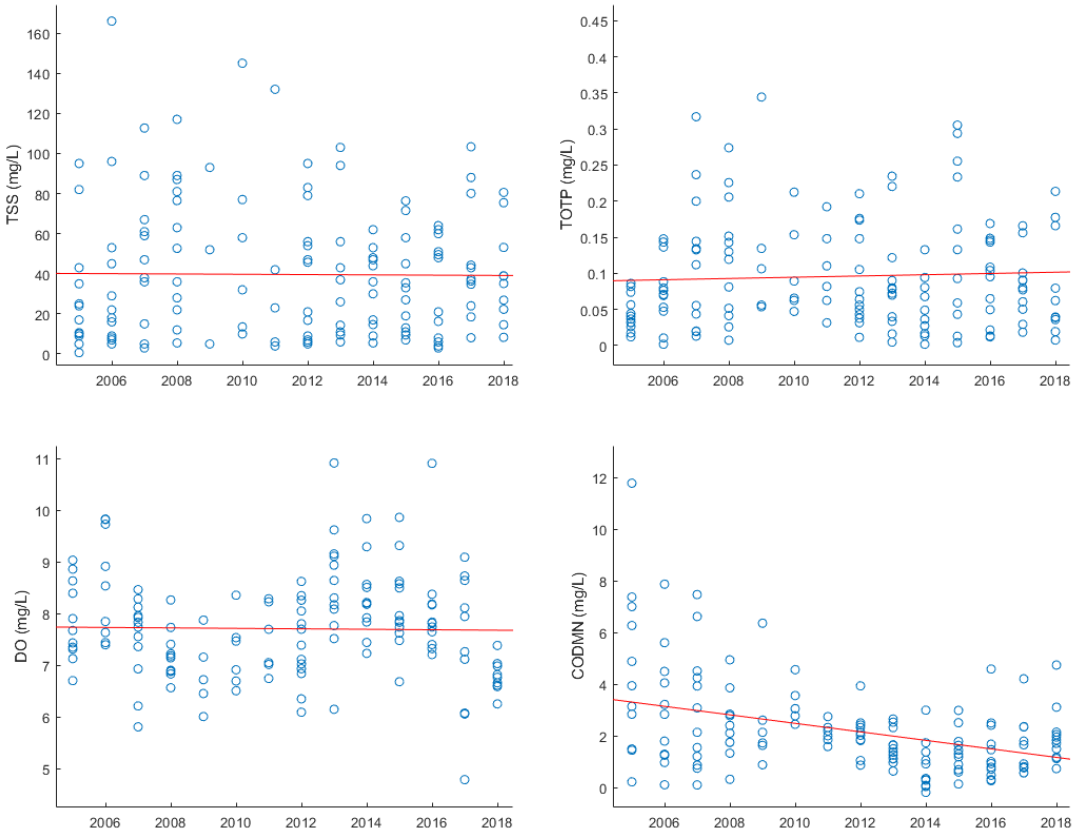


Figure A.4. Temporal trends of key water quality parameters at Lumphat Water Quality Monitoring Station

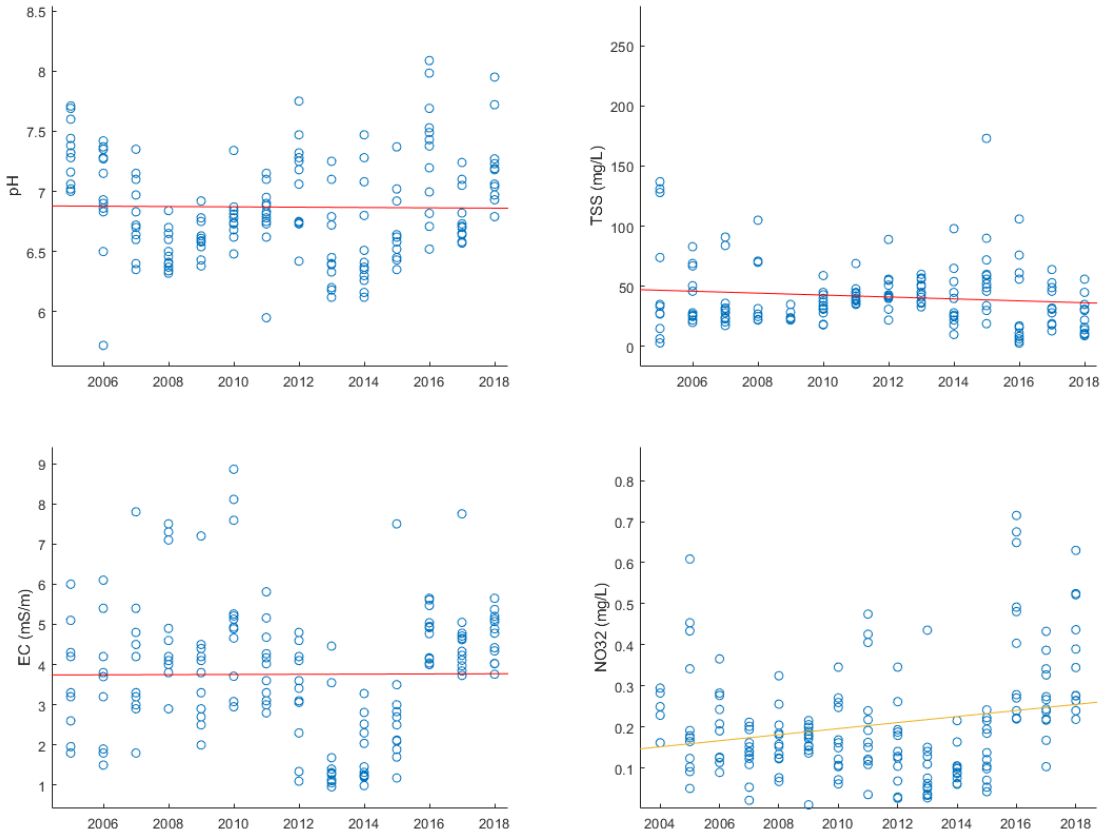
Annex 1.5 Ban Don (Viet Nam)

Table A.5. Trends of key water quality parameters at Ban Don Water Quality Station

Parameters	Unit	Kendall tau values	p-values
pH	-	-0.0858	0.093881
TSS	mg/L	-0.00944	0.8563
EC	mS/m	0.401	24.885e-15
NO_{3-2}-N	mg/L	0.289	1.956e-08
NH_4-N	mg/L	0.142	0.007906
TOTP	mg/L	-0.12	0.022121
DO	mg/L	-0.287	22.3971e-08
CODMN	mg/L	-0.00492	0.92365

Note:

p-value < 0.05 indicates significant change, negative (-) Kendall tau value indicates decreasing trend, and positive (+) Kendall tau value indicates increasing trend.



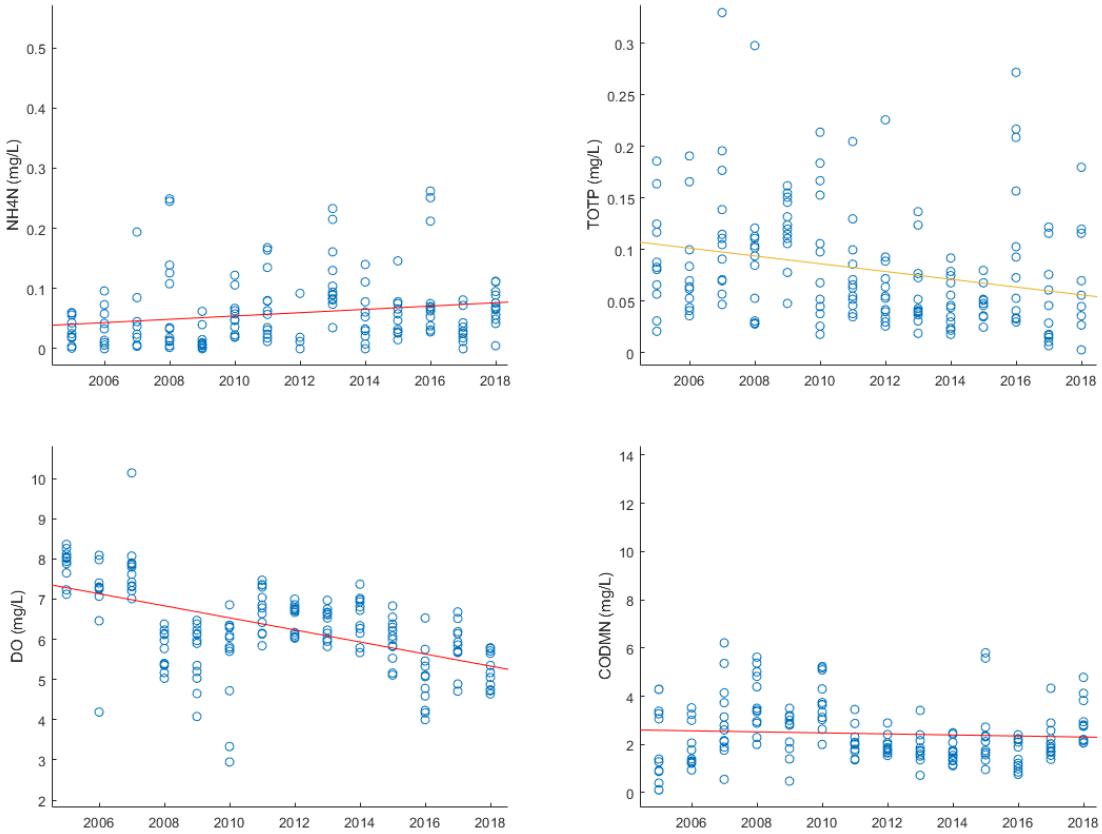


Figure A.5. Temporal trends of key water quality parameters at Ban Don Water Quality Monitoring Station

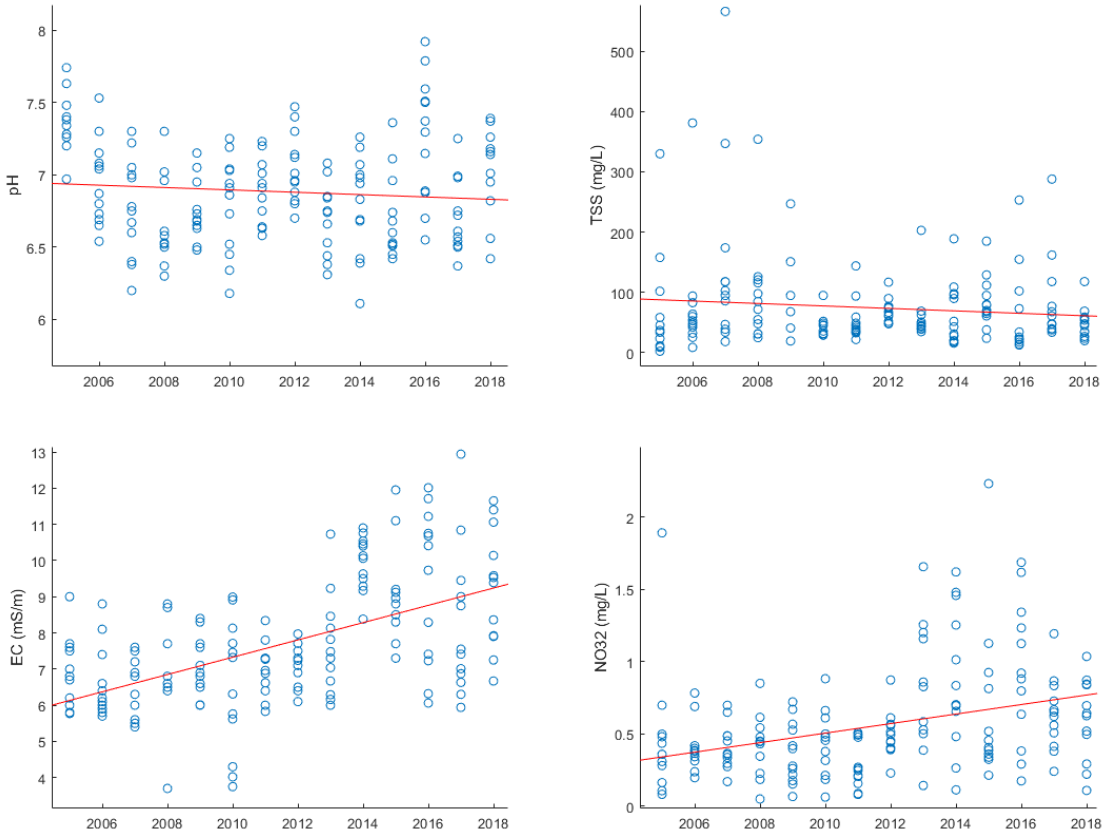
Annex 1.6 Pleicu (Viet Nam)

Table A.6. Trends of key water quality parameters at Pleicu Water Quality Station

Parameters	Unit	Kendall tau values	p-values
pH	-	-0.0361	0.4813
TSS	mg/L	-0.0276	0.60006
EC	mS/m	0.0273	0.59445
NO_{3-2}-N	mg/L	0.127	0.014123
NH_4-N	mg/L	0.139	0.009626
TOTP	mg/L	-0.21	6.8628e-05
DO	mg/L	-0.422	2.2204e-16
CODMN	mg/L	-0.0362	0.4808

Note:

p-value < 0.05 indicates significant change, negative (-) Kendall tau value indicates decreasing trend, and positive (+) Kendall tau value indicates increasing trend.



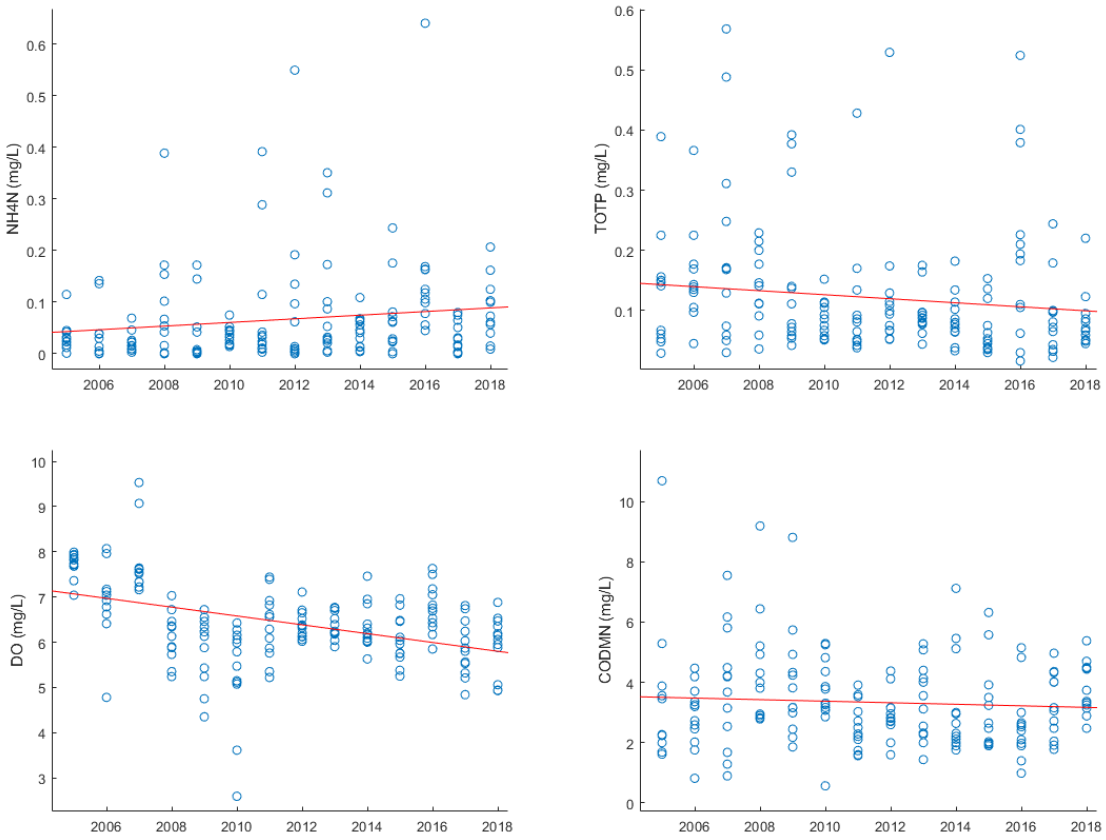


Figure A.6. Temporal trends of key water quality parameters at Pleicu Water Quality Monitoring Station

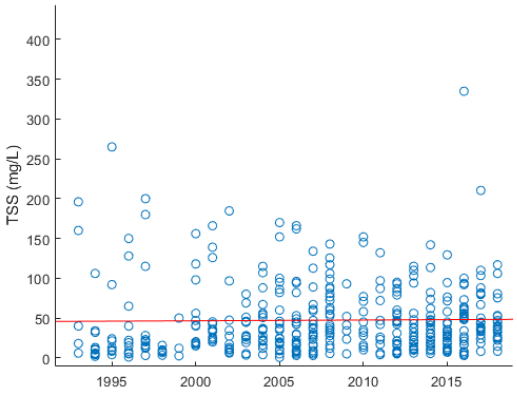
Annex 1.7 Prek Kdam (Cambodia)

Table A.6. Trends of key water quality parameters at Prek Kdam Water Quality Station

Parameters	Unit	Kendall tau values	p-values
pH	-	0.0505	0.12218
TSS	mg/L	0.108	0.0011138
EC	mS/m	-0.0701	20.031549
NO_{3-2} -N	mg/L	-0.0663	0.044425
NH_4-N	mg/L	-0.0663	0.044425
TOTP	mg/L	0.274	2.2204e-16
DO	mg/L	0.277	2.22e-16
CODMN	mg/L	-0.229	2.3481e-12

Note:

p-value < 0.05 indicates significant change, negative (-) Kendall tau value indicates decreasing trend, and positive (+) Kendall tau value indicates increasing trend.



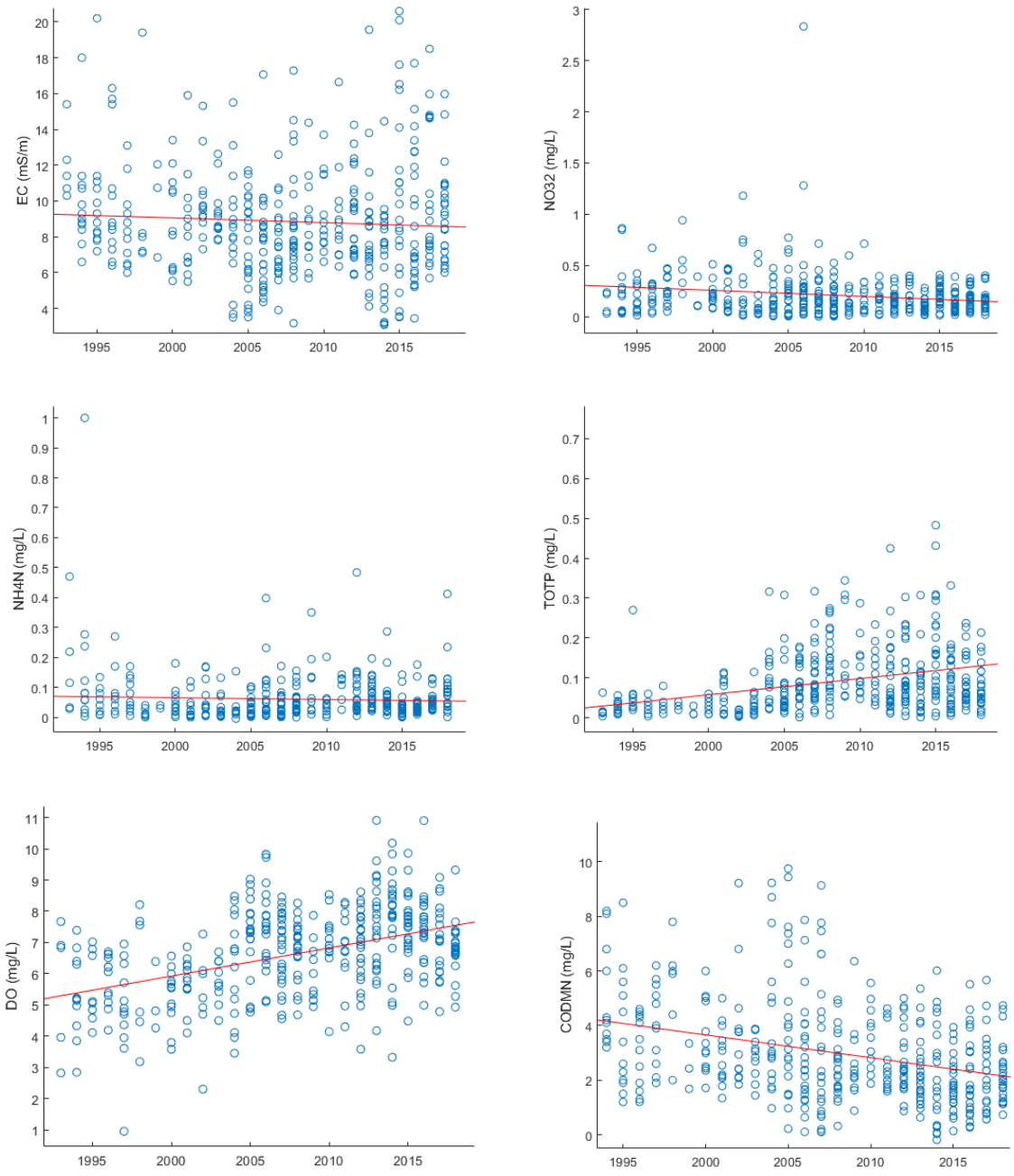


Figure A.7. Temporal trends of key water quality parameters at Prek Kdam Water Quality Monitoring Station

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