META-ANALYSIS OF WATER QUALITY CHARACTERISTICS IN THE LOWER CHAO PHRAYA RIVER, THAILAND

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ABSTRACT

Since August 2016, we have carried out more than two years of on-site observations and water quality analyses in the lower reaches of the Chao Phraya River in Thailand. The water quality characteristics were assessed based on automatically collected water quality and water level data, obtained from the Thai government. In addition to these results, we investigated changes in water quality by comparing our results to those of previously reported field observations and water quality analyses. According to our results, water quality characteristics vary significantly with the season due to changes in natural discharge in the rainy season and constant discharge by the Chao Phraya Dam during the dry season. In the dry season, the salinity intrusion range was larger, with high salinity, and the water had low temperatures and oxygen contents. During the rainy season, the salinity intrusion range was suppressed, and the water had low salinity, high temperature, and high oxygen contents. The longitudinal river pH was alkaline. Previously, the salinity of the water was high from the mouth of the river to a distance of 100 km downstream, and had a high oxygen content at distances from 150 to 350 km from the river mouth and low oxygen near the river mouth. The pH of the water was alkaline longitudinally along the river, with the value decreasing from upstream to downstream. There were no significant differences between the water quality characteristics detected in this study and those reported previously.

Keywords: *mate-analysis, water quality, Chao Phraya River, Thailand*

1. INTRODUCTION

It is important to consider river water quality when evaluating the soundness of rivers for maintenance and management purposes. Also, when water quality deteriorates, such data constitutes a useful baseline for assessing returns to health. Therefore, continuous and regular monitoring is required, but measurement and analysis take a great deal of time, effort, and cost. In developing countries and moderately developed countries, environmental water quality standards remain low, yet many rivers do not satisfy those standards. There are a wide variety of uses for urban water, such as raw water, agricultural water, and industrial water, affecting various socioeconomic factors. However, the improvement efforts made by governments and companies alone are limited, so it is necessary to raise public awareness about environmental improvement.

In Thailand, a middle-income country that has been developing in recent years, standards are not proportional to socioeconomic development, and river water environments have not improved significantly since 1996. In fact, major rivers are deteriorating (WEPA, 2015). The Pollution Control Department (2019) surveyed the water quality index for 52 major rivers in Thailand, and found that water sources in the northeast and central regions are better than in other regions, but in general the water quality is low. The water quality of the Chao Phraya River is deteriorating, and is listed as an area that needs monitoring and improvement. In addition, many water structures are being constructed and operated throughout the Chao Phraya River, resulting in complex changes in water quality. However, water quality monitoring has only been carried out by the government, and little analysis and research has been done.

Therefore, since August 2016, we have been conducting on-site observations and water quality analysis on the lower reaches of the Chao Phraya River in Thailand. We also compared past and present water quality levels, according to the Thai government's automatic water quality and level monitoring results, and those of previous field observations and water quality analyses.

2. STUDY AREA

Figure 1 shows a map of Thailand and the lower Chao Phraya River. Table 1 shows the observation items at each observation point. The Chao Phraya River basin extends from the northern mountainous region of Thailand to the central plain, and has a basin area of 157,925 km^2, which accounts for about 30% of the country and is the largest basin in all 29 provinces. The upper reaches of the northern region are mountainous, the middle reaches are floodplains, and the lower reaches are deltas. The Ping River (36,018 km^2), Wang River (11,708 km^2), Yom River (24,720 km^2), and Nan River (34,557 km^2) flow from the north and merge at Nakhon Sawan, located in the middle reaches, where the Chao Phraya River begins. The Sakae Krang River flows in further from the west, and the Pasak River (18,200 km^2) merges from the east at Ayutthaya and flows out into the Gulf of Thailand (Taichi T. et al., 2015). The Sam Lae water intake (95.1 km from the estuary) is operated in Bangkok, the capital of Thailand, and is

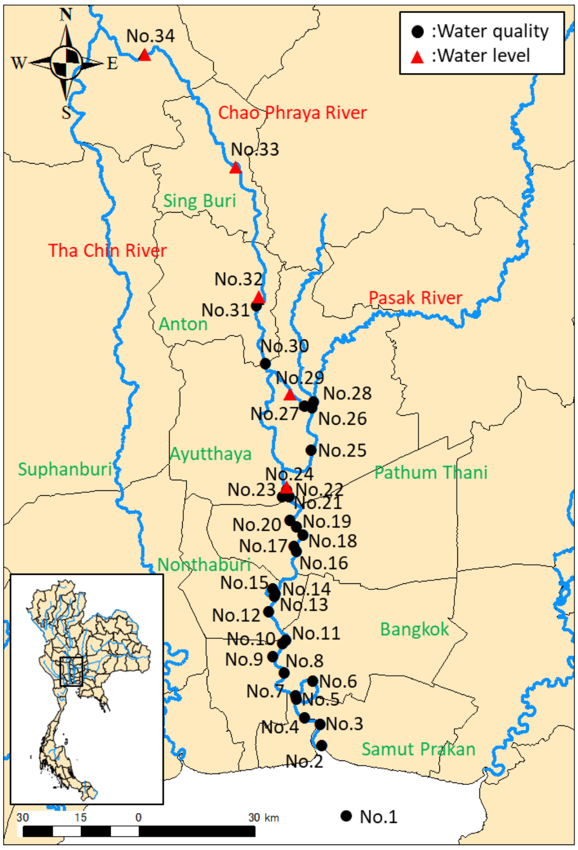

Figure 1. Map of Thailand and the lower Chao Phraya River.

Table 1 The observation items at each observation point.

No	Station Name	Distance from the river mouth (km)	Water level	Logger meter(EC)	2016	2017			2018			Remarks
					Nov.	Mar.	Aug.	Nov.	Apr.	Jun.	Nov.	
					WQ	WQ	WQ	WQ	WQ	WQ	WQ	
1	Sea water	-20.0						◉				TPU
2	The river mouth	0.0						◉				TPU
3	Samut Prakan	6.5						◉				TPU
4	C01_T02	11.3	▲	▲			○	◉	◉	◉	◉	MWA, TPU
5	CP.01	17.6						◉				TPU
6	C02_T01	28.4	▲	▲			○	◉	◉	◉	◉	TPU
7	C03_S06	34.2	▲	▲			○	◉		◉	◉	MWA, TPU
8	Saphan Taksin	44.2			○	○	○	○	○	◉		TPU
9	C04_S07	50.0	▲	▲					◉	◉	◉	MWA, TPU
10	RID	54.5				◉	○	◉	◉	◉	◉	TPU
11	CP.02	55.8						◉				TPU
12	C05_T04	64.9	▲	▲			○	◉	◉	◉	◉	MWA, TPU
13	CP.03	69.5						◉				TPU
14	Wat Klangkret	69.6							◉	◉		TPU
15	CP.04	75.1			○							TPU
16	C06_S04	90.1	▲	▲			○	◉	◉	◉	◉	MWA, TPU
17	CP.05	91.5			○							TPU
18	C07_S01	95.1	▲	▲			○		◉	◉	◉	MWA, TPU
19	CP.06	97.8						◉				TPU
20	C08_S03	100.5	▲	▲			○	◉	◉	◉	◉	MWA, TPU
21	C09_S05	109.3	▲	▲			○	◉	◉	◉	◉	MWA, TPU
22	Bangsai	109.3				◉		◉				C.29A (RID), TPU
23	CP.07	110.9						○				TPU
24	CP.08	112.4			○							TPU
25	C10_T03	131.0	▲	▲			○	◉	◉	◉	◉	MWA, TPU
26	CP.09	143.7			○							TPU
27	CP.10	144.1			○							TPU
28	CP.11	144.6			○							TPU
29	C.35	152.9	▲									RID
30	CP.12	164.9			○							TPU
31	CP.13	183.1			○							TPU
32	C.7A	185.0	▲									RID
33	C.3	229.0	▲									RID
34	C.13	278.4	▲									RID

○:Surface water by TPU
◉:Surface and Riverbed water by TPU
▲: Thai government
※WQ: Electrical conductivity, pH, water temperature, ion chromatography and alkalinity titration

TPU: Toyama Prefectural University
MWA: Metropolitan Waterworks Authority
RID: Royal Irrigation Department

currently operating in brackish waters. Thailand has lowland topographic features. The Chao Phraya River has a very gentle gradient, of approximately 1/50,000 (Taichi T. et al., 2003). Therefore, the brackish area extends from the estuary to 160 km inland (Ayutthaya). During the dry season, the salinity of rivers increases, which has a large effect on tap water in the Bangkok metropolitan area.

3. FIELD OBSERVATION AND ANALYSIS DATA

3.1 Field observation

Field observations (electrical conductivity (EC), pH, and water temperature) and river water and sample collection were carried out at the sampling points and sampling times shown in Table 1. The field observation method is described below.

In November 2016, March, August, and November 2017, and April, June, and November 2018, pH, water temperature, and EC were measured once at each observation site using a portable water quality meter (LAQUAactD-70/ES-70; HORIBA, Kyoto, Japan).

3.2 Dissolved ion analysis

The sampled river water was transported to Japan and analyzed in the laboratory for sodium (Na^+), ammonium (NH_4^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), lithium (Li^+), and chloride (Cl^-), nitrate (NO_3^-), sulfate (SO_4^{2-}), fluorine (F^-), nitrite (NO_2^-), barium (Br^{2-}), phosphate (PO_4^{2-}), and hydrogen carbonate (HCO_3^-) ion contents.

Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, Li^+, Cl^-, NO_3^-, SO_4^{2-}, F^-, NO_2^-, Br^{2-}, PO_4^{2-} were filtered using a 0.45-μm mesh filter and measured using ion chromatography (ICS-2000; Dionex, Sunnyvale, CA, USA).

HCO_3^- was quantified using a titration method using 0.01 mol/L sulfuric acid with a methyl red mixed indicator (color change point pH about 4.8).

3.3 Observation data

The Metropolitan Waterworks Authority (MWA) automatically measures the water level and water quality every hour at points indicated as "MWA" in the remarks column of Table 1. The results are then published online (MWA, 2020). The Royal Irrigation Department (RID) publishes hourly water level and discharge data at each station at the points indicated as "RID" in the remarks column in Table 1 (RID, 2020). In this study, EC, dissolved oxygen (DO), pH, water temperature, and water level data were downloaded and compared to our data. Furthermore, the Thai Meteorological Department publishes the minimum 1-minute weather data online (TMD, 2020). Daily precipitation and temperature data for Bangkok were also downloaded for comparison.

4. FIELD OBSERVATION RESULTS

In this study, we use the definitions of the rainy (May–October) and dry (November–April) seasons used by the Irrigation Department of Thailand for water management.

4.1 pH

Figure 2 shows a longitudinal river pH heatmap from August 1, 2016 to February 13, 2020 based on the MWA automatic observation data. The grayscale map was interpolated using the Kriging method. The pH was 7.2–8.2 along the river, indicating a neutral to slightly alkaline environment. No change in pH was observed between the rainy and dry seasons, but the pH increased along the river from upstream to the estuary. For comparison, Kobayashi (1958) found that the pH of the Chao Phraya River was mostly weakly acidic, in the range of 6.1–

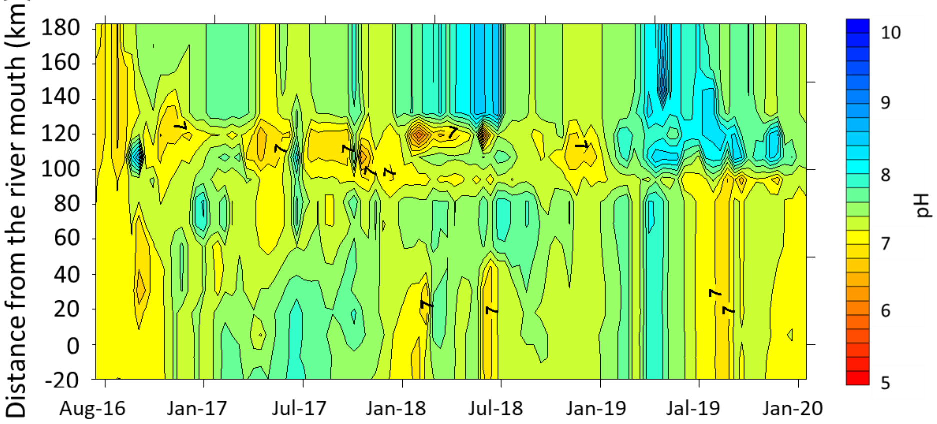

Figure 2 Longitudinal river pH heatmap from August 1, 2016 to February 13, 2020.

7.1. Meanwhile, Mizuno (1977) showed that the overall pH of the river was alkaline, ranging from 7.4 to 8.8, and the value tended to decrease from upstream to downstream.

4.2 EC

Figure 3 shows the EC longitudinal heatmap, longitudinal water level, and Chao Phraya Dam discharge from August 1, 2016 to February 13, 2020 based on MWA automatic observation data. The distance in the legend is the distance from the estuary. The heatmap was interpolated using the Kriging method. The water level was high in the rainy season and low in the dry season. Observatory No.32 C.7A (185.0 km), located in the upstream

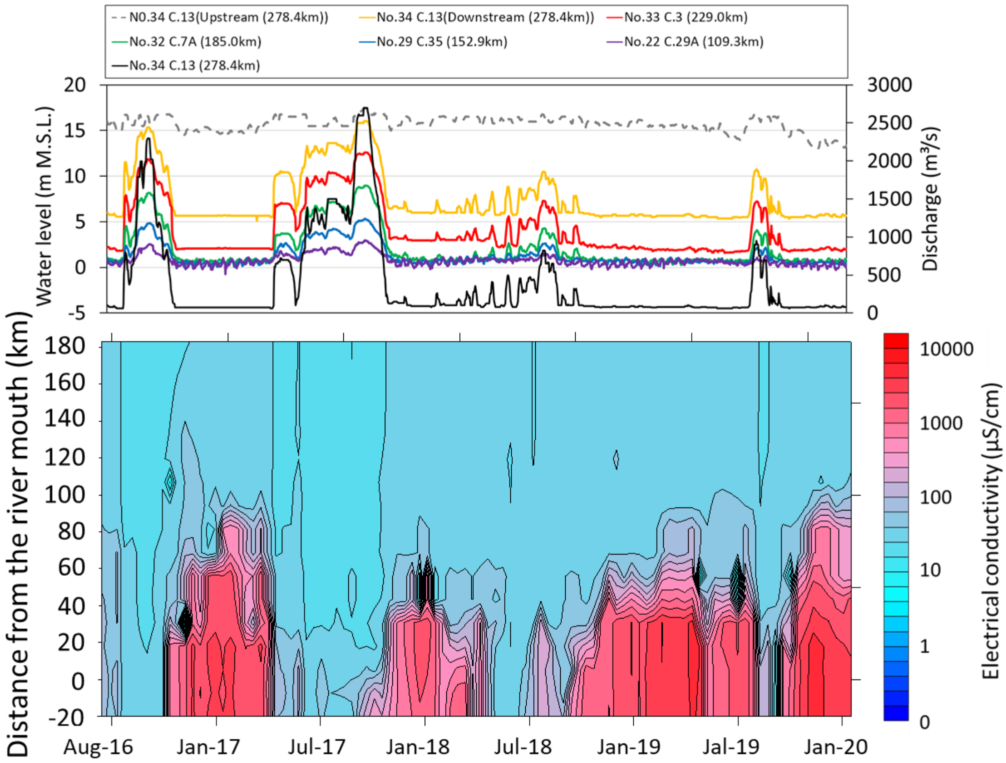

Figure 3 Electrical conductivity longitudinal heatmap, longitudinal water level, and Chao Phraya Dam discharge from August 1, 2016 to February 13, 2020 (Yusuke H. et al., 2019).

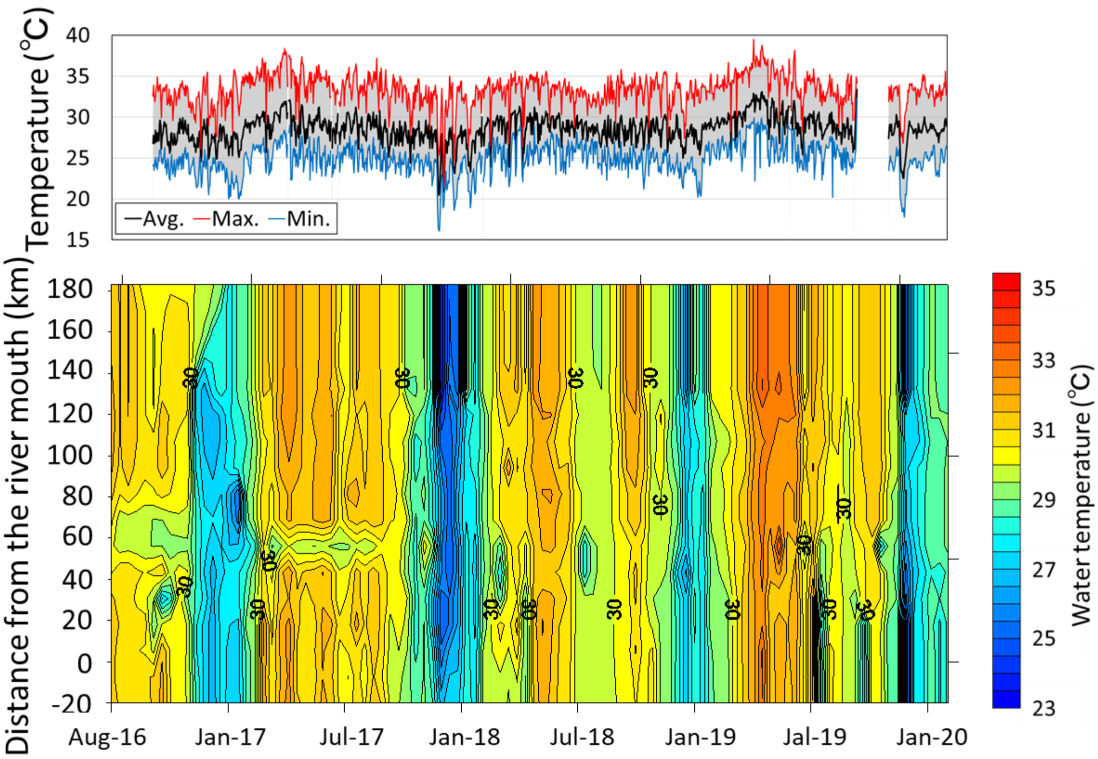

Figure 4 Water temperature longitudinal heatmap from August 1, 2016 to February 13, 2020 and daily temperature in Bangkok.

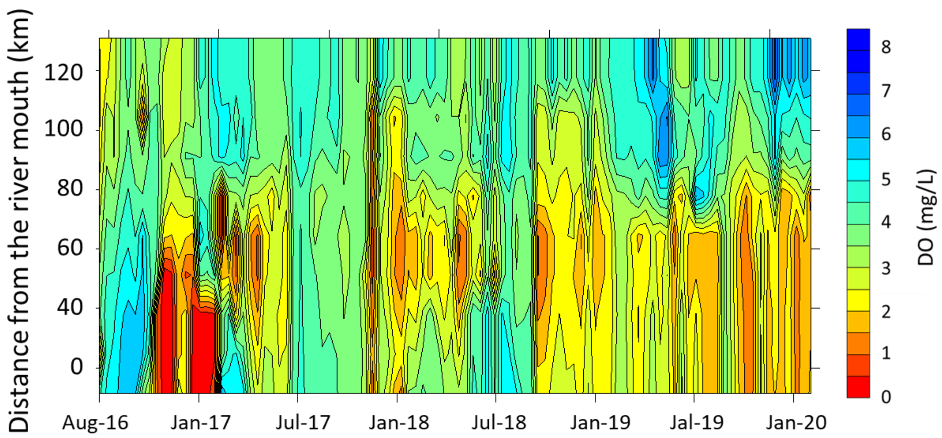

Figure 5 Longitudinal dissolved oxygen (DO) heatmap from August 1, 2016 to February 13, 2020 (Yusuke H. et al., 2018).

Anton province, was affected by the tide level, and the water level changed. Throughout the year, EC exhibited characteristic seasonal changes in response to water level changes during the rainy and dry seasons. EC was low at the high water level in the rainy season and high at the low water level in the dry season. In December 2019, saltwater intrusion was severe due to a drought, and EC increased rapidly at the beginning of the dry season and increased up to 100 km from the estuary. The saltwater intrusion was suppressed as the water level rose in the rainy season, whereas seawater ran up the river during the constant discharge operation in the dry season. At the beginning of the dry season, EC increased markedly up to 64.9 km from the estuary, and seawater had a strong effect up to this point. The peak increase was observed in February, during the dry season, at which point EC increased from 80 km to 100 km from the estuary. Saltwater run-up to the intake (95.1 km) also had an effect. Suzuki (1995) investigated the water quality throughout Bangkok and reported that well water in Bangkok had an EC of 1520 µS/cm.

4.3 Water temperature

Figure 4 shows a longitudinal heatmap of the water temperature from August 1, 2016 to February 13, 2020 and the daily temperature in Bangkok based on MWA automatic observation data. The heatmap was interpolated using the Kriging method. Temperatures ranged from 20 to 37°C throughout the year, and the water temperature was generally between 28 and 34°C. The temperature was highest from the end of the dry season to the beginning of the rainy season (March–May), and from the end of the rainy season to the beginning of the dry season (October–January). In November, which marks the beginning of the dry season, the value was low. The highest values were recorded in the dry season months of March and April and at the beginning of the rainy season, in June. Thus, water temperature, like air temperature, increased at the end of the dry season and decreased at the end of the rainy season.

4.4 DO content

Figure 5 shows the longitudinal DO heatmap of the river from August 1, 2016 to February 13, 2020 based only on MWA automatic observation data. The heatmap was interpolated using the Kriging method. The DO content was high in the rainy season and low in the dry season. Seasonal changes occurred during the rainy and dry seasons throughout the year. In the dry season, the DO content was higher 100 km from the lower estuary, but lower than upstream, increasing to 5 mg/L or more. Pollution by organic matter was considered to be low. In the dry season, from November to April, the DO content was very low, less than 3 mg/L, in the region from the estuary to 80 km. Every dry season, the value was low in the region around 50–80 km from the estuary, which includes Bangkok. During the dry season in 2016, the DO content was 2 mg/L in the region from the estuary to around 80 km away, indicating anoxic conditions. This is thought to be due to the influx of nutrients due to the intrusion of saltwater and the increased oxygen consumption of aquatic organisms. Yoshiaki T. et al. (2007) showed that the DO content was less than 3 mg/L in the region from the estuary to 60 km, and exceeded 5 mg/L at distances greater than 100 km from the estuary.

5. DISSOLVED ION CONTENTS

Figure 6 shows the time series of the main ions found in the river water collected from station No.18. The major ionic components of the river water from July 1956 to June 1957 (Kobayashi, 1958) are also shown. The concentrations of all ions remained almost constant during the rainy season (May–October). In the dry season (November–April), the concentrations of all ions increased. In particular, the Na^+, Cl^-, SO_4^{2-}, Ca^{2+}, and HCO_3^- contents increased significantly more during the dry season than those of other ions (K^+, Mg^{2+}). This was probably because seawater entered the river water due to saltwater intrusion in the dry season. The results from 2017–2018 showed no change in ions during the rainy season, and were consistent with previous results

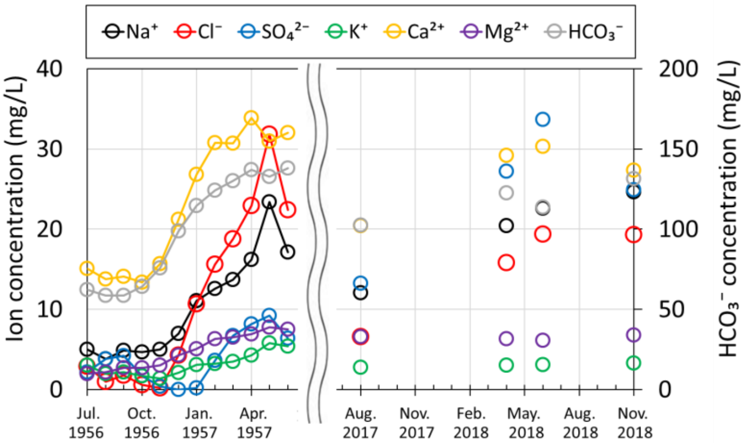

Figure 6 Time series of main ions in the river water collected at station No.18 C07_S01 (95.1 km).

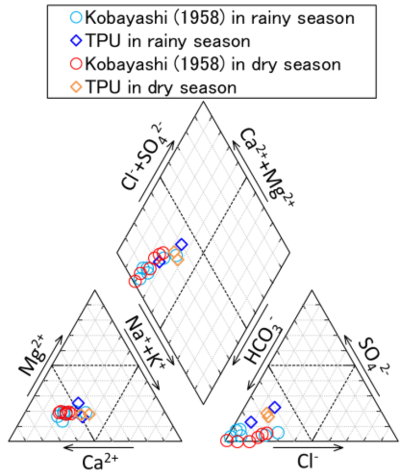

Figure 7 Trilinear diagram of data collected from No.18 C07_S01 (water intake; 95.1km).

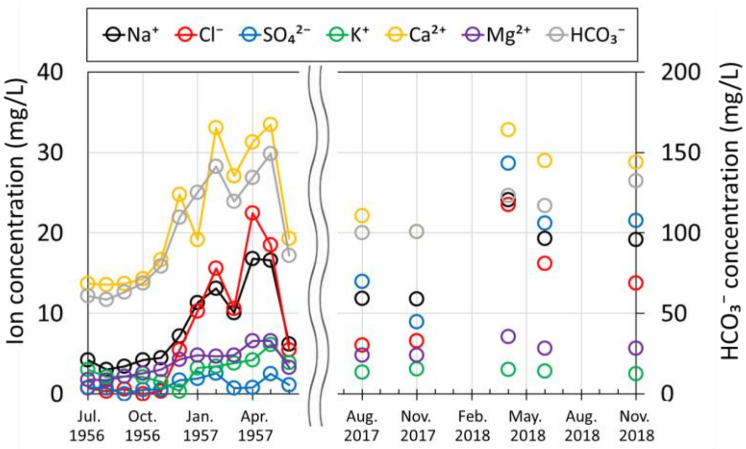

Figure 8 Time series of major river ions in water collected at station No.25 C10_T03 (131.0 km).

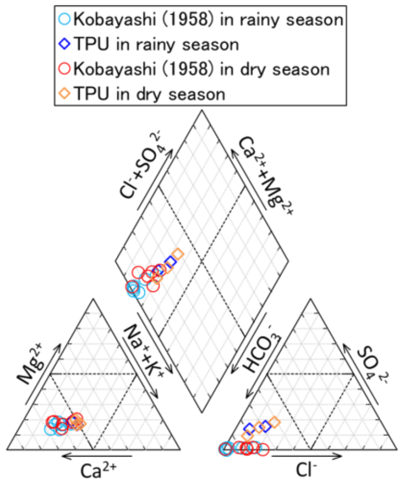

Figure 9 Trilinear diagram of data collected from No.25 C10_T03 (131.0 km).

(Kobayashi, 1958). However, the Na^+, Cl^-, SO_4^{2-}, Ca^{2+}, and HCO_3^- concentrations increased during the dry season. Na^+, Cl^-, K^+, Mg^{2+}, Ca^{2+}, and HCO_3^- did not show significant changes from the previous results (Kobayashi, 1958). However, seawater and SO_4^{2-}, an anthropogenic ion, increased significantly. This is thought to be due to the increase in carbon dioxide emissions and the inflow of acidified rain. Figure 7 shows the trilinear diagram of No.18 C07_S01 (water intake, 95.1 km). Kobayashi (1958) reported Ca-HCO_3 type in both rainy and dry seasons, and our results indicated the same findings. Therefore, our results indicate that the water quality characteristics remain similar to their historic values (Kobayashi, 1958). However, SO_4^{2-} and Cl^- increased compared to Kobayashi (1958). Figure 8 shows the time series of major river ions in the samples collected at stations No.25 C10_T03 (131.0 km) and No.18 C10_T03 (131.0 km) and the major ionic components of river water from July 1956 to June 1957 (Kobayashi, 1958). As in the case of C07_S01 (water intake, 95.1 km), all ion concentrations remained almost constant during the rainy season (May–October), but increased during the dry season (November–April). Compared to historic values (Kobayashi, 1958), there were no significant changes in Na^+, Cl^-, K^+, Mg^{2+}, Ca^{2+}, and HCO_3^- contents, but there were large increases in seawater and the anthropogenic ion SO_4^{2-}. Figure 9 shows a trilinear diagram of the results from No.25 C10_T03 (131.0 km), which indicate that the historic water quality (Kobayashi, 1958) and that of the current water was of the Ca-HCO_3 type. The results also show that SO_4^{2-} and Cl^- levels have increased compared to Kobayashi (1958).

6. CONCLUSIONS

The purpose of this study was to compare the current water quality along the Chao Phraya River to historically reported results based on past field observations and analyses.

The discharge range of the Chao Phraya Dam was restricted during the dry season, resulting in an increase in the range of saltwater run-up, high salinity, low water temperature, and low oxygen. The increase in the flow rate due to the natural discharge from the Chao Phraya Dam during the rainy season suppressed the range of saltwater run-up, resulting in low salinity, high water temperature, and high oxygen content. Thus, seasonal changes are believed to be closely related to the inflow of saltwater due to the difference in discharge from the Chao Phraya Dam. According to the comparison between our results and historic data, there were no significant changes in water quality, except for a significant increase in the concentration of dissolved SO_4^{2-}.

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