Study of Sumida River, Part-1; Its COD and EC characteristics from data collected in spring, 2021

Takao ANDO, Akira ONO, Takumi SHIMADA, Atsuhiro TAKAHASHI,
Tae FUKUSHIMA, Kosuke HOTTA and Mai YAMADA
Teikyo University of Science

Abstract
The Sumida River, a typical urban river in Tokyo, has been recognized as a site for fostering Tokyo's urban life that serves as a venue of leisure and relaxation for its residents. As the Teikyo University of Science (TUS) is located near the Sumida River, students spend a lot of time nearby. Clarifying the characteristics of Sumida River, and teaching it to students, are important not only for enhancing environmental awareness among students, but also local environment conservation. In this study, chemical oxygen demand (COD) and electric conductivity (EC) data, major sources of contamination, and the characteristics of the river were analyzed and interpreted as follows. 1) Although our COD and EC data showed that Sumida River was affected by tidal movement, the river water in our research area (from Otakebashi Bridge to Senju-Ohashi Bridge) might exhibit backward and forward movements, and it was slightly affected by sea water from the Tokyo Bay. 2) Major chemical contaminant sources of investigated area were determined to be the Miyagi wastewater purification facility (WPF) and the Mikawajima WPF at the upstream and downstream sides of the TUS, respectively. 3) We presume a two-fraction zone in the Sumida River from our analytical results and public data, including a "high COD zone" with an upstream stagnant zone upper the Shirahige Bridge, and a "low COD zone" with a downstream flush zone under the Shirahige Bridge. Raising environmental awareness concerning the urban river among its residents presumably might contribute to maintaining its clean and safe environment. We came to conclusion that the importance of educating the citizens about keeping urban rivers environmentally clean and safe for the future generations.

Keywords: COD; EC; Sumida River; environmental education

I. Introduction

Urban rivers are exploited not only for water utilization purposes but serve as symbolic places of leisure and relaxation for citizens all over the world. In Japan, urban rivers were designed as peculiarly safe protection facilities for flood. During the period of Japan's rapid economic growth, urban rivers were thought for only drainage and canal for material transportation from factories. Although urban rivers have been equipped with water conservancy facilities that ensure the safety of river banks, with high retaining walls along the riverside, the overall interest in rivers among its residents has gradually waned. However, due to the environmental degradation in the 1960s and the related environmental pollution, there has been a growing concern among its residents with keeping Tokyo's urban rivers cleaned.

The improvement of the environment around rivers is recognized as a very important aspect for modern urban life. The Sumida River, being a typical urban river in Japan, has been extensively studied. Previous studies have examined the aspects of the assumed pollution load by sewage contamination[1)], flow forecasting[2)], and some summarized tidal characteristics[3)] of the Sumida river. It is underlined that the quality of river water needs to be determined by studying the dissolved oxygen (DO) and nutrient salt concentrations, and that remediation should be carried out using derivatives of coal ash[4)] and other materials[5)]. Educational applications for university students at the Kiso River[6)], the Nagano Prefecture, and the local community at Kameta River[7)] in Hakodate City, Hokkaido, have also been previously reported. These studies demonstrate that rivers could serve as helpful tools for environmental education for people of all ages as it provides them with exposure to the natural environment and that such awareness can help solve regional environmental issues.

The Teikyo University of Science (TUS) is located next to the Sumida River, and students naturally spend a lot of time near it. In this study, Sumida River's chemical oxygen demand (COD) and electric conductivity (EC) were measured at several locations near the TUS, and continuous measurements were collected every 2 hours over 1 d to determine the major drivers of contamination variability.

Understanding the river contamination through our investigation will surely help enhance environmental awareness among students. Moreover, a holistic understanding of rivers by the students would lead to future improvements of the local environment and would positively influence the next generation of children. It would be necessary to interpret the river as a connecting tool between our daily life and natural environment. Environmental education for the younger generation should be urgently desired from the standpoint.

II. Characteristics of the Sumida River and the Public Surveillance System

1. Overview

The Sumida River is separated from the Arakawa Waterway at the Iwabuchi Water Gate, Kita Special Ward, Tokyo. It flows to Tokyo Bay through seven municipalities (Kita, Adachi, Arakawa, Sumida, Taito, Chuo, and Koto special wards), confluent with the Shakujii and Kanda rivers, from north to south (Fig.1). It is administrated by the Tokyo Metropolitan Government. The length of whole flow path of the Sumida River is 23.5 km, while the basin area covers 690.3 km^2, including the Shingashi River, which is a tributary is the upper basin of Sumida River. The population of the basin area attains about 3 million, it is an unprecedented urban river through the center of a large city in the world.

During the period of Japan's rapid economic growth, as a substantial amount of wastewater from residential buildings and industrial facilities were discharged into the Sumida River, the water quality has substantially degraded. To save the lives and properties of residents, a high concrete river bank was erected to isolate the river. Consequently, citizen's

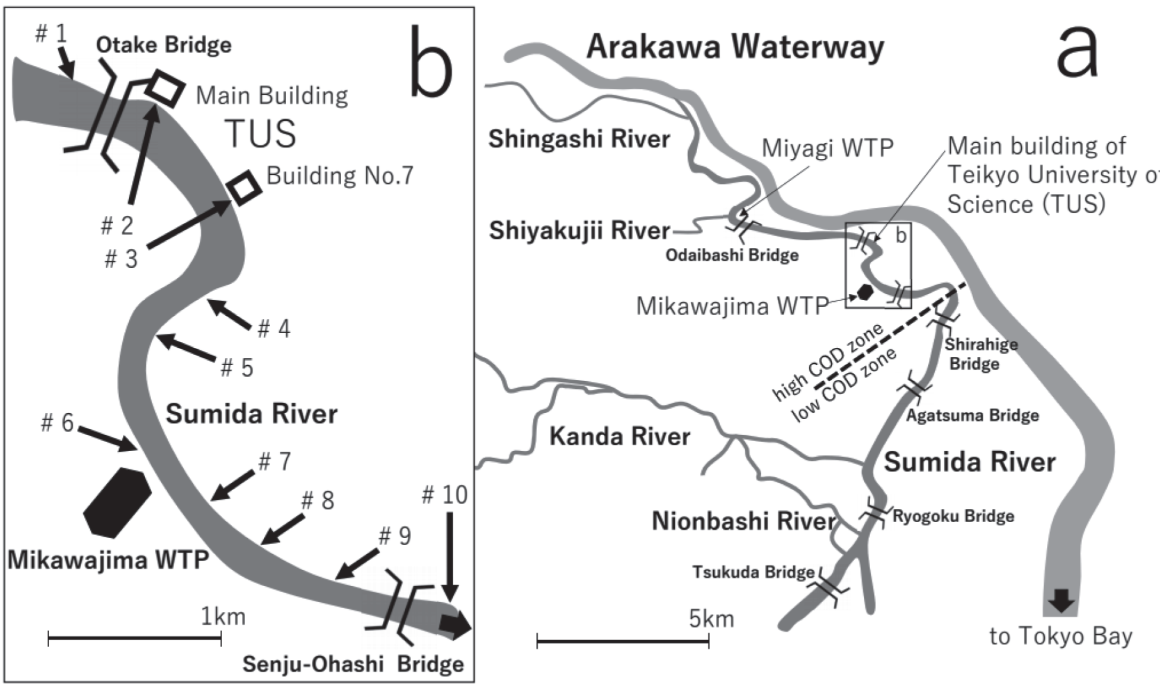

Fig.1 Schematic map of the study area with the rivers, wastewater purification facilities (WPF), and bridges. Locations of 10 sampling points are shown (#1-#10), continuous sampling for 24hrs was performed at #3 in front of building No.7 of the TUS.

interest in urban rivers declined due to the water pollution and the loss of logistic infrastructure. Since then, the water quality of the Sumida River has gradually improved owing to the consolidation of the sewerage system and dredging of the riverbed. And so-called "Super embankments" and "Terraces" alongside rivers which were planned to get affinity with urban river have been playing an important role in enhancing people's awareness toward rivers.

It is very difficult to observe streamflow and to estimate stream quantity because the Sumida River is affected by tidal movements[3]. There are many sources of river water, such as confluence rivers, including the Shakujii River and the Kanda (Nihonbashi) River, and river water purification facilities (WPF). There are 20 WPFs in Tokyo. The WFP chemical survey data of influent and effluent waters are shown on the Tokyo metropolitan government's homepage[8]. WPF facilities along the main stream of the Sumida River and its confluent rivers were Shingashi, Ukima, Miyagi, Mikawajima, and Higashioku which was an additionally advanced sewage treatment facility at Mikawajima (Fig.1). Representative facility's influent and effluent water's chemical analysis data are shown in Table 1.

Table 1 COD concentration of influent and effluent wastewater from wastewater purification facilities (WPF) around TUS.

	Influent	Effluent
Ukima WPF	69	7
Miyagi WPF (Shiyakujii series)	89	9 (west)
Mikawajima WPF (Oku series)	80	10 (general)

2. Surveillance System

The Tokyo Metropolitan Government, the Ministry of Land, Infrastructure, Transport and Tourism, and the governments of Hachioji City and Machida City cooperated to conduct water quality surveys in 105 rivers, at 50 points in marine areas, and at 2 points in lakes for every year. For the main stream of the Sumida River, the monthly chemical composition of the river water was investigated under five bridges: Odaibashi, Shirahigebashi, Agatumabashi, Riyogokubashi, and Tukudaohashi. The main parameters of the survey were wind direction and speed, stream regime, flow rate, astronomical phenomenon, air temperature, river water temperature, color phase, odor, and transparency. According to the Japan Environmental Standards, the water parameters related to living standards include pH, DO, biological oxygen demand (BOD), COD, suspended solids (SS), coliform bacteria count, total nitrogen (T-N), and total phosphorus (T-P). The observed COD trend[9] from February to April 2020 is shown in Fig.2 (the horizontal axis is set as per the distance of each bridge to Tokyo bay).

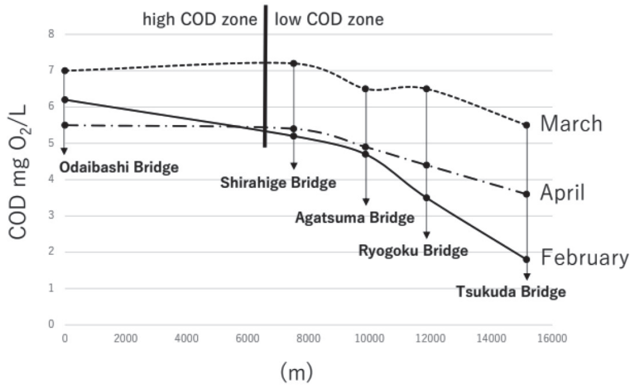

Fig.2 COD trend based on regular surveillance by the Tokyo metropolitan government from February to April, 2020. The horizontal axis indicates the sampling point's distance from Tokyo Bay.

The same type of surveys were regularly conducted by the Liaison Council of Purifying Action of the Sumida River"[10]. This council was organized by nine municipalities (Chuo, Taito, Sumida, Koto, Kita, Arakawa, Itabashi, Nerima, and Adachi Wards) alongside the Sumida River and its tributaries, such as the Shingashi, Shakujii, and Shirako rivers. The surveyed parameters included transparency, pH, DO, BOD, COD, SS, chlorine ion (Cl-) concentration, T-N, T-P, and ammonium nitrogen (NH_4^+-N). This survey was conducted at the previously mentioned locations by the Tokyo Metropolitan Government in September (flooded season) and February (drought season).

III. Methods

1. Methods of Collecting River Water

River water was collected using a self-made water sampler made of rope and a 5 L bucket. Two 1 L plastic bottles were co-washed using river water and then filled with the water collected in the bucket. One bottle was used for chemical analysis immediately after sampling, while the other one was kept in a refrigerator for re-measurements. The measured parameters were air temperature, river water temperature, flow direction, and flow velocity, while the surface and surrounding environmental conditions at the riverside were noted simultaneously.

a Sampling at 10 Locations.

Ten samples were collected at 10 different locations on the riverside from Otakebashi Bridge to Senju-Ohashi Bridge (Fig.1 b). The first location was set downstream of the Miyagi WPF, and the final location was set downstream of the Mikawajima WPF (the distances between two points > 2.5 km). The sampling at the lowest tide was conducted at 11:33; on March 29, 2021 (during a clear day), to determine the transport of chemicals from the upper stream of the river. Average air and river water temperatures were 23.6 and 17.8°C, respectively (all the data are shown in Appendix 1).

b Continuous Sampling for 24hrs at #3

Continuous sampling was performed for 24hrs at location #3 in front of building No.7 of the TUS (see Fig.1b). Each sample was collected at 2 h intervals from 14:00, March 21 until 12:00, March 22, 2021. The air and river water temperatures are shown in Appendix 2. At location #3, it was difficult to observe the conditions of the river surface and surrounding area at night, as it was raining. Due to the raining, the flow direction and velocity were not measured at #3. The Sumida River flowed back during the sampling period, when the low tide changed to high tide, allowing the chemical influences from the downstream region to be evaluated.

2. Analytical Procedures

The sampled river water in 1 L plastic bottles was filtered using a 5A filter attached to a Buchner funnel with a vacuum system. After adjusting the temperature to 25 ±2°C in a water bath, and portable analytical meters of pH (Lutron Multi Water Quality Checker PH-230SD with Lutron PH electrode PE-11), EC (Lutron Multi Water Quality Checker WA-2017SD with Lutron Conductivity Probe CDPB-03), DO (same WA-2017SD with Lutron Dissolved Oxygen Probe OXPB-11), and turbidity (Shiro Industry Handy turbidity meter M2700ZB-170T) were used for each measurement. COD analysis was carried out using the official method based on JIS K 0102.

In the permanganate method, a predetermined amount of sulfuric acid, silver nitrate, and potassium permanganate were added to the sample and reacted under 80°C, and the amount of permanganate consumed was converted into the amount of oxygen.

Our procedure is shown in Fig.3 as follows: 1) 100 mL of a filtered sample was placed in a conical flask, 2) 10 ml H_2SO_4 (1+2), 5 ml $AgNO_3$ (20%), and 10 ml $KMnO_4$ (5 mmol) were added, followed by stirring. Then, 4) the mixture was kept in a boiling water bath for 30 min, 5) 10 ml $Na_2C_2O_4$ (12.5 mmol) was added, and 6) titration was performed at 60–80°C.

The main reactions are shown below.

① Redox reaction of the sample

$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

$3Mn^{2+} + 2MnO_4^- + 2H_2O \rightarrow 5MnO_2 + 4H^+$

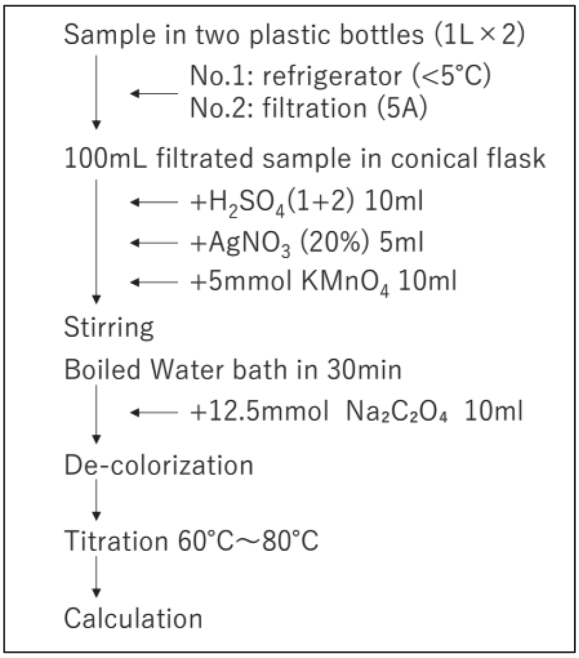

Fig.3 Analytical procedures of COD based on JIS K 0102. H_2SO_4(1+2) means that 1 L of concentrated sulfuric acid with 2 L of water was diluted to 6mol/L.

② Titration reaction

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$
$$MnO_2 + C_2O_4^{2-} + 4H^+ \rightarrow Mn^{2+} + 2CO_2 + 2H_2O$$
$$5C_2O_4^{2-} + 2MnO_4^- + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

IV. Results and Discussion

1. Analysis Results from 10 locations

EC and COD were analyzed at 10 locations (Fig.4) and yielded the following results.

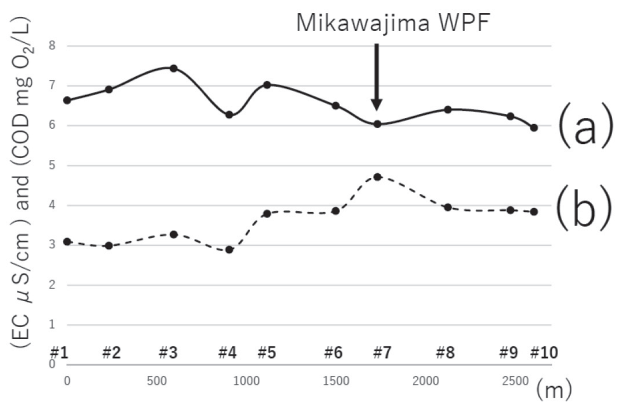

Fig.4 Analysis results of 10 samples of COD (a) and EC (b). The horizontal axis indicates the distance at the sampling point between #1 (base point) and #10 shown in Fig.1.

EC analysis led to the following results:

1) EC data exhibited an increasing trend from the upstream to downstream due to the vicinity to Tokyo Bay. The trend indicated that the Sumida River was affected by tidal movement, thus agreeing with previous studies[3)].
2) Sample #7, collected close to the Mikawagima WPF, displayed a slightly higher value that expected from the increasing trend. This can be explained by the effect of chlorine ions from the hypochlorite treatment of the Mikawagima WPF. Although the river was thought to flow towards Tokyo Bay during the low tidal period, we concluded that the river flow stagnated or that it slowly shifted to the other direction.

COD analysis led to the following results:

1) The COD concentration exhibited a decrease in downstream flow, thus marking the existence of a trend opposite to the EC trend. Sample #7 yielded a higher value compared to the other data trends, but similar to the EC trend. This might have been caused by the discharged treated wastewater from Mikawagima WPF, which discharged treated water with 10 mg COD. These data also indicate that the river flow either stopped or slowly shifted its direction.
2) Since the samples were collected at the time of low tidal conditions, the river flowed towards Tokyo Bay. Therefore, the contaminant source of COD was located in the upstream area (perhaps at the Miyagi WPF, which discharged treated water with 10 mg COD).
3) Fig.2 shows that the total COD trend of the Sumida River decreased downstream. In particular, the area downstream from Shirahige Bridge exhibited a steeply decreasing trend compared to the upstream area. Thus, the downstream side of Shirahige Bridge was affected by seawater dilution.

At the same time, the COD concentration in the area upstream from Shirahige Bridge was nearly constant. Our analytical results show a harmonious trend with this constant trend. As the river channel of the Sumida River is steeply curved in the upper area of Shirahige Bridge, sea water could not flow up under the Shirahige Bridge, thus the area upstream of Shirahige Bridge was not directly affected by seawater. Therefore, we presume that the river flow stopped or moved slowly in the study area.

2. Continuous Sampling over 24hrs at #3

The EC and COD analytical results of the continuous sampling are shown in Fig.5.

We observed a harmoniously-changing trend between tidal movement and EC data during the 24hrs period. This trend indicated that the Sumida River was affected by tidal movement, and the trend is consistent with the results of the analysis. When fresh ocean water went upstream of the river, the EC data would have peaks that were higher than our empirical estimates. Although the river water in this area was affected by tidal movement, the water could only circulate backwards and forward within this area.

The COD trend also exhibited a harmonious trend with that of the tide (except at four points after 06:00 on March 23). As there was a weak rain at 0:00 (March 22), data around this time might have been affected by the rainfall. During another observation period, it was

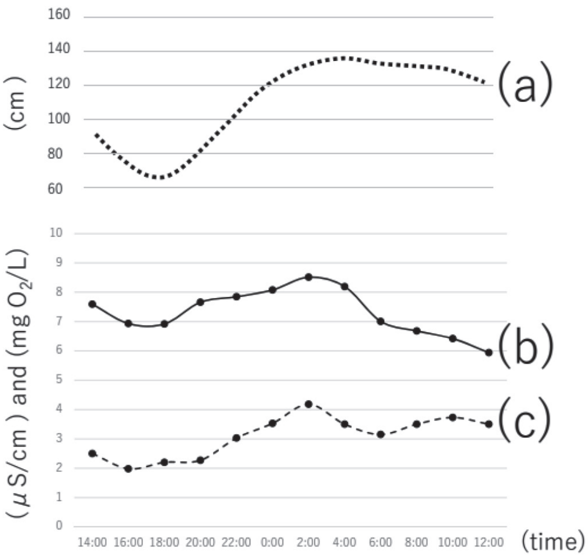

Fig.5 Tidal movement of Tokyo Bay (a) and 24hrs continuous sampling analysis results of COD (b) and EC (c) at #3.

observed that pollution tended to increase with the rising tide. This trend indicated that there may be a pollution source downstream that released a high COD concentration, which was considered to be the Mikawashima WPF.

3. Characteristics of Water in the Sumida River and Future Tasks of Our Study

There were chemical contaminant sources both upstream (Miyagi WPF) and downstream (Mikawagima WPF) the TUS in the Sumida River. Although the river water in this area was affected by tidal movement, the water could only circulate backwards and forward within this area, being slightly affected by sea water from Tokyo Bay. The high COD trend was consistent until Shirahige Bridge, where the Sumida River mostly flows from northwest to southwest.

Conversely, in the downstream area of Shirahige Bridge, the river water was directly affected by sea water from Tokyo Bay, thus COD seemed to decrease gradually to Tokyo Bay (Fig.2). In this study, we propose a two-fraction model of Sumida River: “the high COD zone” where upstream and stagnant zones were observed until Shirahige Bridge, and “the low COD zone” that was downstream of Shirahige Bridge.

The Sumida River is an urban river with a low dip, and a large volume of water originates from water treatment facilities. In particular, in the high COD zone, there were many WPFs and the river water was stagnant, causing the quality of the river water to be driven by the quality of water treatment.

The future objectives of our study will be to 1) conduct a continuous monitoring of not only previous analytical items, such as COD and EC, but also T-N and T-P to check the environmental quality of river water, 2) examine the demand for more high-quality wastewater treatment by the Tokyo metropolitan government, 3) investigate new and original methods of wastewater treatment, and 4) analyze new bottom sludge treatment for smooth flow without dredging.

Finally, one of the main implications of our study is to re-link people's environmental awareness with the river, and (ultimately) to recover a scenic urban environment. Therefore, we need to introduce environmental education in schools in order to keep urban rivers environmentally clean and safe for the future generations.

As the first investigation of Sumida River, further research with different seasons would be planned for more detail understanding for its characteristics.

V. Conclusion

The water in Sumida River was analyzed at ten locations (#1~#10) and 24hrs of continuous sampling at #3 to obtain the following results.

1) Although the investigated area (from Otakebashi Bridge to Senju-Ohashi Bridge) was affected by tidal movement, river water could only circulate backwards and forward within this area, being slightly affected by the sea water from Tokyo Bay.
2) Upstream of Miyagi WPF and downstream of Mikawagima WPF were presumed to be the major source areas of chemical contamination in the area around the TUS in the Sumida River.
3) In this study, the analytical results of river flow, tidal movement, and contaminant trend of COD, all suggest that a two-fraction model of the Sumida River can be proposed: (a) a high COD and stagnant zone upstream of Shirahige Bridge, and (b) a low COD flush zone downstream of Shirahige Bridge.
4) The objectives of our future studies will be as following: a) continuous monitoring of various chemical parameters including T-N and T-P, b)

examination of the demands by the Tokyo metropolitan government for higher quality wastewater treatment, and c) investigation of new and original methods of wastewater and bottom sludge treatment to achieve better environmental protection.

It is of vital importance in raising environmental awareness among the residents concerning river purification in the urban areas. To do so, environmental education should first be introduced in public schools as part of school curriculums simultaneously to teach that urban rivers are to be kept environmentally clean and safe for the future generations.

References

1) Kazuo Fukushima, Hideshige Takada and Takahisa Hanya: An Environmental Study of Urban Rivers - a Case-Study of the Sumida River in Tokyo, Comprehensive urban studies, No.21, P.21-38, 1984
2) Yasuo Nihei, Tomoyuki Takamura and Noriyuki Watanabe: Issues on Discharge Monitoring in Main Influent Rivers into Tokyo Bay, Proceedings of Coastal Engineering, Japan Society of Civil Engineers, vol. 54, P.1221-1225, 2007
3) Masashi Kawamura, Masato Okabe, Tadashi Yamada: A Study of Characteristic of Water Quality and Flow in Tidal Area of Urban Rivers, Journal of the Institute of Science and Engineering. Chuo University, No.14, P.73-83, 2009
4) Daiki Kakinuma and Tadashi Yamada: Comparative experiment of sediments improvement material in tidal urban river, Journal of JSCE F (Environment), vol.73, No.5, P. I_353-I_359, 2017
5) Yuki Morimoto, Toshihiro Hayashi, Kenji Nakamoto, Tadashi Hibino: Evaluation of organic properties of the sludge remediated by alkaline granulated material, Journal of JSCE B1 (Hydraulic engineering), vol.73, No.4, P. I_1219-I_1224, 2017
6) Kentaro Nozaki: A plan and estimation of river and stream investigation study on the course of nursery and primary school teacher education, Japanese Journal of Ecology, vol. 62, P.51-58, 2012
7) Kuniaki Tanaka: A Challenge to the Preservation of the Local River Environment through the Environmental Education -Overview form the historical environmental problems and their solutions of Kameda River in Hakodate City-, Jounal of Hokkaido University of Education (Natural Sciences), vol.69, No.1, P.21-36, 2018
8) Bureau of Sewerage of Tokyo metropolitan government: Preliminary figures of discharging quantity from waste water purified center of Tokyo government at Febuary, 2020, https://www.gesui.metro.tokyo.lg.jp/business/pdf/r0302kubu.pdf, (Reference date: April 28, 2021)
9) Environmental Bureau of the Tokyo Metropolitan Government HP: Result of a measurement of public water and water area (preliminary report), https://www.kankyo.metro.tokyo.lg.jp/water/tokyo_ bay/measurements/news_flash.html, (Reference date: April 28, 2021)
10) Liaison Council of Purifying Action of Sumida River HP: Business report, 2017, https://www.city.itabashi.tokyo.jp/_res/projects/default_project/_page_/001/006/052/r1-sumida.pdf, (Reference date: April 28, 2021)

Appendix 1
COD and EC data of 10 locations analysis at 11:33 at March 29, 2021. Average air and river water temperature were 23.6°C and 17.8°C.

location	COD (mgO_2/L)	EC ($\mu S/cm$)
No.1	6.63	3.09
No.2	6.91	2.99
No.3	7.43	3.27
No.4	6.27	2.89
No.5	7.02	3.79
No.6	6.50	3.86
No.7	6.04	4.71
No.8	6.40	3.95
No.9	6.23	3.88
No.10	5.95	3.84

Appendix 2
COD and EC data of 24 hours continuous sampling at March 22-23, 2021.

Sampling time	Temperature (°C)		COD (mgO_2/L)	EC ($\mu S/cm$)
	Air	River water		
14:00	14.5	18.0	7.59	3.36
16:00	13.3	18.0	6.93	1.96
18:00	12.0	17.1	6.92	3.12
20:00	11.0	17.5	7.66	3.24
22:00	8.9	16.2	7.85	4.44
0:00	8.5	16.5	8.08	5.17
2:00	8.1	16.5	8.51	5.93
4:00	7.0	15.0	8.19	5.50
6:00	6.0	12.2	7.01	4.70
8:00	9.0	15.2	6.68	4.85
10:00	13.0	17.1	6.42	5.02
12:00	15.5	18.1	5.94	5.01