https://doi.org/10.20965/jdr.2021.p0415

Review:

The Trend in Measures Against Urban Inundation in Japan

Hiroyuki Kato†

The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
†Corresponding author, E-mail: h_kato@env.t.u-tokyo.ac.jp

[Received October 5, 2020; accepted December 6, 2020]

All over Japan, damage has occurred from flood from inland waters. Because the measures against urban inundation should be promoted swiftly and economically, the Ministry of Land, Infrastructure, Transport and Tourism has implemented policies to push forward efficient and effective mitigation measures. Such comprehensive policies combine tangible and intangible measures and select prioritized areas for implementation. In June 2020, forecasting methods for probable maximum rainfall were announced, taking heavy rain and climate change into consideration. Furthermore, because a sewer system itself can be damaged from heavy rain, measures have been adopted to make a water-resistant sewerage system. In this manner, various policies in Japan address measures against urban inundation.

Keywords: pluvial flooding, sewerage system, urban development, sewerage policy

1. Introduction

Recently, frequent floods were attributed to climate change and other reasons. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [1], in most of the middle-latitude countries extreme precipitation becomes highly intensified and it is projected to worsen by the end of the 21st century. Damage may increase due to the increase of annual rainfall. The Japan Meteorological Agency (JMA) credits global warming with the "heavy rain in July 2018" [2]. This is the first time that the JMA made reference to the influence of climate change in terms of heavy rainfall. As shown in **Fig. 1**, damage from river flooding is serious in Japan. The value of the damage caused by flooding in Japan from 2008 to 2017 amounts to about 1.8 trillion JPY (173 billion USD). However, the flood from inland waters triggered by insufficient drainage capacity of sewerage systems accounts for 40% of all flooding in the country. Especially in metropolitan Tokyo, floods from inland waters account for about 70% of all floods in the city.

Alleviating the urban inundation caused by climate change is a worldwide challenge. This study aims to optimize rainfall management, by combining information on water quality and levels in urban areas [3], to formulate efficient policy that considers the influence of climate change on rainfall variations and the economy [4, 5].

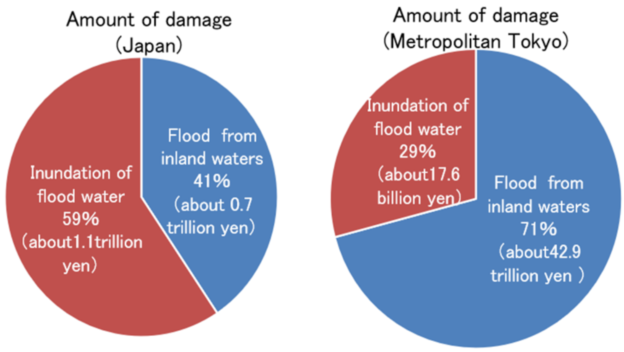

Fig. 1. Breakdown of flood damage (classification of statistics of flood damage from 2008 to 2017).

Municipalities implement sewerage systems in Japan. The projects are financially supported by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) for the municipalities that implement efficient drainage system projects.

This paper reviews the significance of the policies against urban inundation, which were established over the last 10 to 15 years. Furthermore, it examines the latest policy trends from a long-term viewpoint, taking climate change into consideration. As for the measures against urban inundation, various projects, technical developments, and research studies have been conducted. However, there are four basic concepts (see **Fig. 2**). The policy viewpoints of these concepts are reviewed.

2. Basic Concepts of Measures Against Urban Inundation in Japan

Preventing urban inundation is one of the objectives stipulated in the Sewerage Service Act. Mitigation steps have been implemented throughout Japan. As shown in **Fig. 3**, in recent years heavy rain has been more frequent. The impermeable urban area has increased with the advancement of urbanization. The risk of damage from urban inundation has increased. In fact, large-scale damage

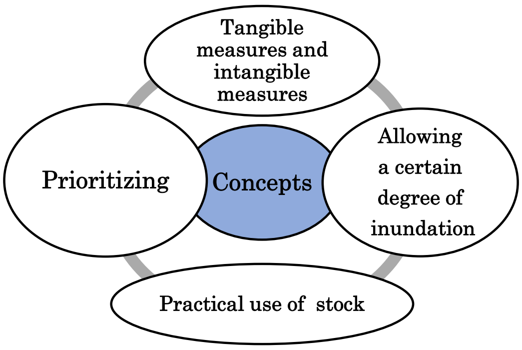

Fig. 2. Four concepts of measures against urban inundation.

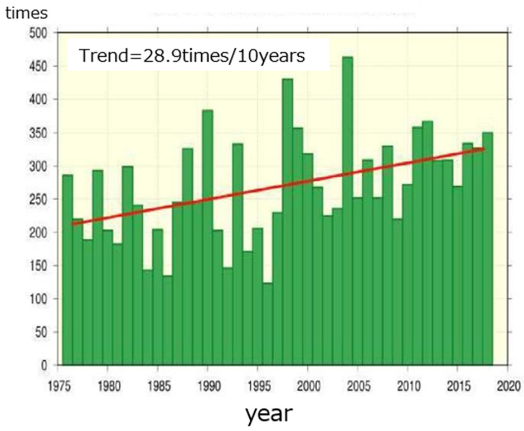

Fig. 3. Frequency of rainfall events that amount to 50 mm or more per hour (nationwide).

occurs regularly. However, due to the increased cost of social security for the aging (among other reasons), it is difficult to secure from both the Japanese Government and the local public bodies the budgetary support for public works. For this reason, new policies are sought urgently to implement low-cost and highly effective measures against urban inundation. In 2004, MLIT formulated new concepts for the measures against urban inundation.

About 15 years have passed since the formulation of these concepts, but they are the basis for many of today's policies. First, the concepts are explained below.

2.1. Comprehensive Policies Combining Tangible and Intangible Measures

As urbanization increases, the number of occurrences of high intensity rainfall increases; the impermeable area increases and rainwater outflow increases. This causes increased risk of damage from inundation. Local public bodies are not financially equipped to manage these situations. In Japan, measures have been implemented for a long time to improve the infrastructure. However, adopting only tangible measures would be costly and time consuming. Accordingly, also important "intangible measures" were adopted to have residents evacuate quickly and a flood hazard map for inland waters was prepared. This large policy shift accepts the idea that all the risks could not be mitigated only by infrastructure.

2.2. Selection of High Priority Areas for Implementation of Measures Against Inundation

This concept prioritizes tangible implementation based on high priority locations where damage has already occurred or is expected to occur. For example, underground shopping malls and the area around a terminal station were prioritized based on public safety and social impact. Before this concept was adopted in Japan, measures presupposed equal rainfall intensity across regions. Accordingly, this concept represents a large policy shift. Although there is good reason to prioritize areas, there was strong opposition to this approach from the local public bodies. As managers of sewerage works, they are accountable to the citizens. Thus, local public bodies must explain their prioritization based on vulnerabilities. However, to eliminate life-threatening damage within the limited range of municipal budgets, this policy is now being implemented throughout the country.

2.3. Allowing a Certain Degree of Inundation

The third concept is accepting minor damage from inundation. This is a very challenging policy shift. Before adoption of this idea, the system was expected to completely drain all the rainwater, leaving no runoff. However, facilities rarely have this capacity. In order to establish capacity for a large-scale rain event, a large (and costly) facility must be constructed. Moreover, the full capacity of such a facility would be used infrequently. Thus, in determining the capacity of a facility, this concept introduces the idea that a certain degree of inundation is allowed.

For example, in the case of inundation below floor level, life-threatening danger is minimal and the amount of damage to property tends to be contained. For this reason, the idea that inundation below floor level is allowed was introduced into the sewerage facility plans. Yet, the local public bodies raise opposition. Although the scale of damage is minimal, it is extremely difficult for local public bodies to explain this to citizens.

2.4. Maximum Practical Use of Stock

It takes time and money to establish a new facility. Accordingly, the concept of maximum practical use of the capacity of the existing facilities was introduced (i.e., how to operate a facility in coordination with other sewerage facilities). The MLIT has applied this concept to infrastructural inundation measures, as well as to road construction. Regarding the measures against urban inundation, the concept is not limited to efficient use of the existing sewerage facilities by using information and communication technology (ICT), but it includes coordination with an urban development project, such as a river management project and establishment of a water storage facility.

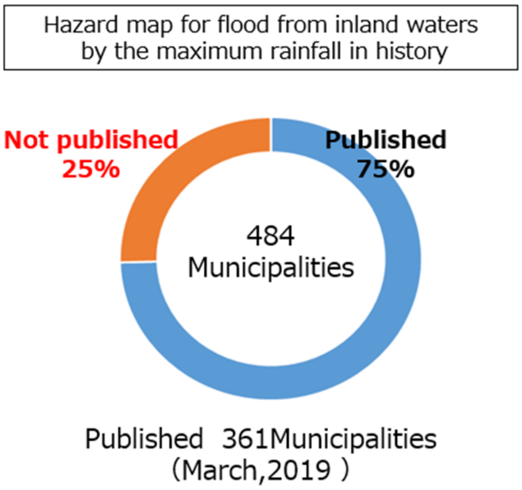

Fig. 4. Publication of hazard map for flood from inland waters.

Four concepts of the new policies to mitigate inundation swiftly and cost effectively (**Fig. 2**) change the existing concepts and are not easily understood by the local public bodies that manage sewerage facilities on behalf of citizens. Due to increasing social security costs, there are budgetary constraints for public work projects. Under the circumstances, citizens are aware of the increased damage from heavy rain and they are conscious to "protect life." The policy trends behind this concept are described below.

3. Trend of Intangible Measures

3.1. Flood Hazard Map for Inland Waters

As mentioned above, it is important to promote and enhance intangible measures that minimize damage. Of the 484 local public bodies necessary to formulate the hazard map for inland water floods, 361 bodies (or 75%) have already formulated a flood hazard map for inland waters, estimating from the maximum rainfall record (**Fig. 4**) [6].

As for the underground shopping mall where life-threatening damage could be caused, the MLIT demands the formulation of a flood hazard map, assuming the maximum-scale rainfall, not estimating from the maximum rainfall record of the place where underground shopping mall exists. Ten local public bodies are listed to formulate the hazard map within the 2020 fiscal year. The maximum-scale rainfall is defined as the maximum rainfall that can be assumed scientifically. This value is determined by estimating from the national rainfall record (different from the maximum rainfall record). Different from the rainfall (which has a long duration) used in river flooding, the maximum-scale rainfall (with short duration) used in projecting floods from inland waters, which has smaller temporal and spatial characteristic deviation. In other words, according to studies, an extremely heavy rainfall that has occurred in one part of the country could occur elsewhere [7].

In recent years, inland waters were not discharged, because of the high water-level of the river into which sewerage is normally discharged. That causes flood from inland waters. Therefore, it is increasingly necessary to consider both the flood from inland waters and river flooding. Furthermore, it is necessary to map the hazard of flood from inland waters, taking the variation of river levels into consideration.

3.2. Observation of Water Level and Provision of Information

It is also important to practically use a map for urban development. Concretely, it is necessary to conduct flood risk evaluations of flood from inland waters for several external forces, like the probable rainfall and the maximum rainfall record. Results could be provided to those involved with urban development projects.

In July 2019, the MLIT requested that real estate developers exhibit the hazard map for the area where the housing and land is located, before making real estate deals.

In the amendment of the 2015 Flood Prevention Law, a system was established that a manager of sewerage works shall actively cooperate in evacuation activities of sites like the underground shopping mall where life-threatening damage could be caused by floods. In this system, a manager of sewerage works shall observe the water level of manholes in real time, using ICT. In case the water-level rises to dangerous heights, the manager shall notify the Disaster Prevention Division of the municipality concerned and facilitate safe evacuation. In May 2020, the system was first applied to the Hakata Station in Fukuoka City.

4. Promoting the Formulation of the Comprehensive Plan for Rainwater Management

4.1. Outline of the Comprehensive Plan for Rainwater Management

To implement the above-mentioned regional prioritization for inundation mitigation the MLIT instructs the local public bodies throughout the country to formulate a "Comprehensive Plan for Rainwater Management." In the previous rainwater plan, an uniform target level was set (**Fig. 5**), but in the Comprehensive Plan for Rainwater Management the basic items, such as the areas sewerage measures and targets are determined according to the risk of inundation in each area (**Fig. 6**). The MLIT provides the financial backing to the local public bodies for the measures required in this plan.

4.2. Formulation of Rainwater Management Plan Taking Global Warming into Consideration the Latest Trend

There is a total of 1,700 local public bodies in Japan. In the areas necessary to take the measures for rainwater of the annual exceedance probability of 1/5, 59% of

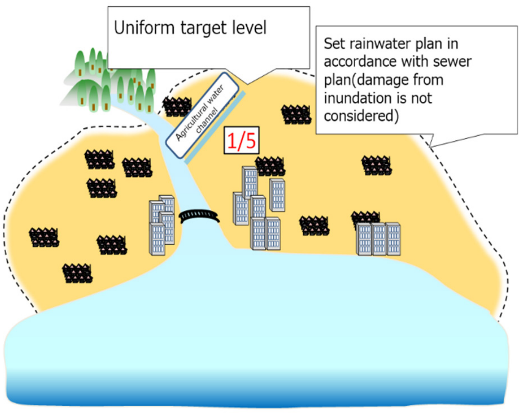

Fig. 5. Previous rainwater plan.

Table 1. Magnification of rainfall variation according to region.

Region	RCP2.6 (increase 2°C) (provisional value)	RCP8.5 (increase 4°C)
Northern Hokkaido, Southern Hokkaido, and North-West Kyushu	1.15 times	1.5 times
Okinawa etc.	1.1 times	1.3 times (provisional value)
Another 12 regions	1.1 times	1.3 times

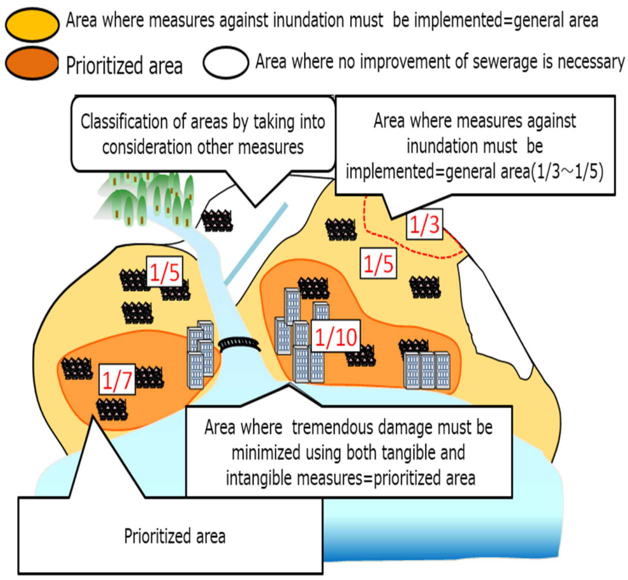

Fig. 6. New rainwater management plan.

the area has already completed the planned upgrades [6]. The long-term objective of these policies is to implement tangible and intangible inundation mitigation measures against the maximum record rainfall. As mentioned above, the maximum-scale of rainfall should be set in the hazard map for inland waters in the area with an underground shopping mall, where life-threatening damage could be caused.

At the time of the 2019 Typhoon Hagibis (Typhoon No.19), tremendous damage occurred from the inundation caused by flood from inland waters. Also, sewerage facilities were also damaged, influencing civilian life significantly. In the future, measures against inundation should be promoted from a long-term perspective, taking climate change into consideration in advance to prevent disaster. To respond to this request, the "Study Group on Urban Inundation Countermeasures Based on Climate Change" was established to review the measures against urban inundation. As for the abovementioned Comprehensive Plan for Rainwater Management, the study group meeting on June 2020 confirmed that a plan should be formulated from a long-term viewpoint, taking climate change into consideration [8]. From the proposal, a new assumption about the probable maximum rainfall used for facility improvements is explained below.

In the Fifth Assessment Report of the IPCC [1], there are four scenarios for greenhouse gas emissions. These scenarios are termed as the "Representative Concentration Pathways Scenario" (RCP Scenario). The average surface temperature in the world is estimated to rise by 2.6 to 4.8°C in RCP8.5 Scenario (an increase of 4°C). This scenario assumes that if greenhouse gas emissions continue as they are now, the total greenhouse gas emissions would double by the end of the 21st century, in comparison to levels before the Industrial Revolution. Also, it is estimated to rise by 0.3 to 1.7°C in RCP2.6 Scenario (a 2°C increase). Therefore, the emission of greenhouse gas would become almost zero at the end of 21st century and the process of global warming would be contained.

To improve data prediction in the future and to set the characteristics of the sewerage plans needed for climate change, the estimated stormwater flow is found by multiplying the probable maximum rainfall, which is now used for improvement of the tangible measures by the magnification of rainfall variation. This method is examined based on "the recommendation about hydraulic control plans based on climate change" [9] that is the recommendation on the hydraulic control examined prior to consideration of urban inundation measures. The magnification of rainfall variation in RCP2.6 Scenario corresponds to an increase of 2°C and is regarded as the provisional value converted from the RCP8.5 Scenario, which corresponds to an increase of 4°C (**Table 1**). This is because the current climate change prediction model has limitations in reproducing the rainfall and rain area. Rainfall duration and urban climate must be considered in the sewerage plan appropriately. The abovementioned method is to be reviewed further by accumulating new knowledge in the future.

Because on announcement of this idea, it is necessary to formulate and review the Comprehensive Plan for Rainwater Management with a long-term perspective based on future climate change. As mentioned above, in reviewing

Fig. 7. Drainage pump vehicle of Kawagoe City.

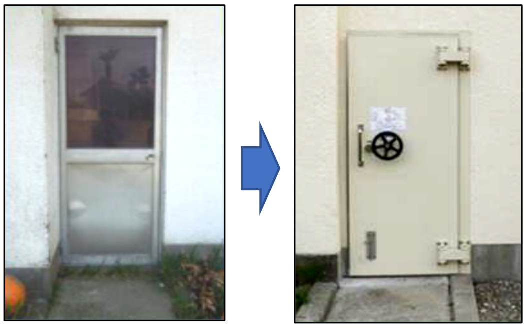

Fig. 8. Making entrance door watertight.

the plan the probable maximum rainfall now used for improvement of the tangible measures is to be multiplied by the magnification of rainfall variation of a long period of time. However, as for a method of how to handle the influence of climate change in the plan, an increase of 2°C is to be considered at the moment, based on the Government in the Paris Agreement goals and the durable life of a sewerage facility.

5. Maximum Practical Use of Existing Facilities

Not only to proceed with establishing facilities, but also to minimize the risk of inundation in an early stage, efforts are made to optimize the operation of existing facilities. Concrete recommendations include practical use of the pumps (they have been allocated as reserve at the time of failure) and a drainage pump vehicle (**Fig. 7**) to move flexibly to the location of inundation.

To control the rainfall and outflow, which vary over time, it is also necessary to use efficient capacity flows into the existing river and to plan for the capacity of the sewerage facility reciprocally. It is important to improve the operability of the sluice gate by exchanging information between the river manager and the sewerage manager. Accordingly, it is effective to install observation and control equipment, such as remote control, water gauge, and monitoring camera using ICT, so that an operator could remotely operate equipment in case of emergency.

Storage of rainwater in buildings is also carried out in an urban development project under the cooperation of city planning measures for flood mitigation. However, mainly the regulations of the local public bodies require an urban developer to install such equipment and there is little benefit for an urban developer. Therefore, as an incentive for a building owner to actively install such equipment, the MLIT notifies the leading local public bodies with jurisdiction to examine increases of ground area ratios in the urban development project. Doing so contributes to the measures against inundation and storage equipment will be installed in September 2020. This is regarded as unprecedented cooperation between urban flood mitigation and urban development, which previously operated under the harmful practice of segmented administrative systems.

Foreign countries promote research and practical implementation of green infrastructures [10]. Although green infrastructure has not spread throughout Japan, measures for urban landscaping and containment of stormwater are being implemented simultaneously, using green infrastructure in Yokohama City and other municipalities. Moreover, the idea of the "hydraulic control of basin" [11] (i.e., efforts to store stormwater by all the stakeholders who are engaged in the activities throughout the basin) is a key policy for the future.

6. Promotion of Waterproofing of Sewerage Facilities

In the 2019 Typhoon Hagibis flood event the sewerage facilities were damaged severely. Sewerage facilities are significant infrastructures, required to promote drainage and pumping during river flooding and to minimize the social impact of damage to a sewerage facility. These policies are described in this chapter.

Because sewerage is a system to collect wastewater using gravity flow, the facility is often located in low lying areas that overlap with hazardous flood areas. About 50% of all the sewerage treatment plants in Japan and about 70% of all the pump stations are in hazardous flood zones. As of December 2019, waterproofed sewerage treatment plants and the pump stations account for only 14% and 15%, respectively [6]. The inundation depth is ordinarily set based on the lifetime of the facility, by supposing river flooding would occur with the medium and high frequent annual levels at the probability of 1/30 to 1/80 [8]. In the case of inundation depth exceeding the goal, sewerage functions should be restored swiftly using the intangible measures by Business Continuity Plan (BCP). Reviewing the layout of important equipment and the structure of construction, it is necessary to proceed efficiently with the measures, by combining relocation of electric equipment to upper floors, updating equipment to waterproof specifications, waterproofing the whole building (**Fig. 8**), and waterproofing prioritized areas.

The MLIT notified the local public bodies that within the fiscal year 2020 they should review the BCP, including facility protection and intangible measures. This should include review of their sewerage facilities at a high risk for flood damage and they should formulate the waterproofing plan, including revising the inundation depth goal, prioritizing flood zones, and proceeding with waterproofing improvements in fiscal year 2021.

7. Conclusion

This paper describes the new flood policies (i.e., the basic concepts of the measures against urban inundation by the sewerage works in Japan), as well as the system of policies based on these concepts and the probable maximum rainfall due to global warming.

In recent years, unprecedented heavy rain occurs almost every year and the damage from inundation is caused by inland waters throughout the country. It is necessary to promote policies that respond to such conditions. Various urban inundation models should be developed.

Real-time data should be collected using new modelling technology to steadily advance this research.

References:

[1] The Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2014: Synthesis Report – Summary for Policymakers," The 5th Assessment Report of IPCC, 2014.

[2] Japan Meteorological Agency, "Heavy rain in July 2018 and record high temperature characteristics and factors after mid-July," 2018, https://www.jma.go.jp/jma/press/1808/10c/h30goukouon20180810.html (in Japanese) [accessed December 20, 2020]

[3] S. Shisheger, S. Duchesne, and G. Pelleter, "Optimization methods applied to stormwater management problems: a review," Uraban Water J., Vol.15, No.3, pp. 276-286, 2018.

[4] N. Kang et al., "Urban Drainage System Improvement for Climate Change Adaptation," Water, Vol.8, No.7, Article 268, 2016.

[5] P. Willems et al., "Climate change impact assessment on urban rainfall extremes and urban drainage: Methods and shortcoming," Atmospheric Research, Vol.103, pp. 106-118, 2012.

[6] Ministry of Land, Infrastructure, Transport and Tourism, "Recommendation about promotion of measures against urban inundation by sewerage based on climate change (reference material)," (in Japanese) [accessed December 20, 2020]

[7] H. Kato et al., "How the assumed maximum-scale rainfall should be considered in estimates of landside inundation," J. of Japan Sewage Works Association, Vol.54, No.653, pp. 96-104, 2017 (in Japanese).

[8] Study Group on Urban Inundation Countermeasures Based on Climate Change, "Recommendation about promotion of urban inundation countermeasures by sewerage based on climate variability," June 2020 (in Japanese).

[9] Technical Study Group on Hydraulic Control Plans Based on Climate Change, "Recommendation about hydraulic control plans based on climate change," October 2019 (in Japanese).

[10] L. Hoang and R. A. Fenner, "System interactions of stormwater management using sustainable urban drainage system and green infrastructure," Urban Water J., Vol.13, No.7, pp. 739-758, 2016.

[11] Ministry of Land, Infrastructure, Transport and Tourism, Social Infrastructure Development Council, and River Subcommittee Report, "Flood disaster countermeasures based on climate change: conversion to hydraulic control of basin by all stakeholders throughout basin," July 2020 (in Japanese).

Name:
Hiroyuki Kato

Affiliation:
Project Associate Professor, The University of Tokyo

Address:
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Brief Career:
2018- Director of Sewerage Planning, The Ministry of Land, Infrastructure, Transport and Tourism
2020- Project Associate Professor, Sewage System Innovation Lab, The University of Tokyo

Selected Publications:
- "Operational Improvement of Main pumps for Energy-Saving in Wastewater Treatment Plants," Water, Vol.11, No.12, Article 2438, 2019.
- "Management of Water and sewage in France," Japan Water Newspaper Corporation, 2020 (in Japanese).

Academic Societies & Scientific Organizations:
- Japan Society on Water Environment (JSWE)
- International Water Association (IWA)