別紙４－１（課程博士（英文））

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Abstract（Doctor）

Title of Thesis	Evaluation of Hourly Household Water Consumption and Free Residual Chlorine Decay in a Water Distribution Network Using Smart Water Meter Data

Approx. 800 words

Access to safe drinking water is vital for public health, yet challenges remain. Developed countries ensure high water quality standards through regulations and technology, while inadequate infrastructure threatens water quality in developing regions. Efficient management and monitoring of consumption patterns are crucial for sustainability amid urbanization. Japan, known for its advanced water infrastructure and continuous monitoring systems, maintains high tap water safety standards. The installation of smart water meters, enabled by digital technology, provides hourly data, unlike traditional manual readings. The smart water meters allow early issue detection, demand forecasting, and better water management, enhancing distribution efficiency and decision-making in water quality control.

Ensuring water safety requires not only monitoring consumption but also maintaining adequate levels of disinfectants, such as chlorine, throughout the distribution network. Chlorine is widely used for drinking water disinfection due to its cost-effectiveness and pathogen control efficiency. However, chlorine naturally decays over time due to chemical reactions within bulk water and interactions with pipe materials. Maintaining sufficient chlorine residuals is necessary to prevent contamination. The rate of chlorine decay is influenced by initial chlorine concentration, temperature, retention time, and pipe material. Regulatory guidelines, such as those set by the World Health Organization (WHO) and Japan's Waterworks Act, establish minimum chlorine concentration standards to ensure public health safety. In Japan, tap water must contain at least 0.1 mg/L of residual chlorine, while 0.4 mg/L is recommended to maintain taste quality. However, bulk and wall decay mechanisms often cause chlorine levels to drop below the required limit, necessitating effective monitoring and management strategies.

This study analyzed hourly household water consumption in the Iride–Chibata district of Kosai City and investigated chlorine decay mechanisms in the Chibata district water distribution network, leveraging smart water meter data and EPANET 2.2 simulations. A total of 1871 households in the Iride–Chibata district were equipped with smart water meters, and their water consumption data in September 2022 were collected for analysis. Based on total estimated consumption, 227 single households were identified and further classified into staying-at-home and going-out households. The analysis revealed that weekend consumption was higher than weekday consumption, with morning (7:00–11:00) and evening (18:00–22:00) peaks reflecting daily routines. The evening peak exceeded the morning peak, likely due to the Japanese evening bathing culture. Moreover, going-out

households exhibited peaked consumption at 8:00 and 20:00 on weekdays and 9:00 and 19:00 on weekends. Further analysis of single-household categories found that going-out households consumed 10% more water on weekends than on weekdays, with a 262% increase in consumption between 13:00 and 16:00. These findings suggest that household routines significantly impact water demand, emphasizing the importance of adjusting water distribution schedules to match peak consumption patterns. The results contribute to sustainable water supply planning, supporting demand-driven distribution and effective disinfection strategies.

Chlorine bulk and wall decay as it travels through distribution pipelines. To determine the bulk decay coefficient (K_b), bottle tests were conducted using the Arrhenius theory on water samples from the distribution inlet of the Chibata district over seven days at temperatures ranging 5, 10, 15, 20, 25, 30 ^oC. The results showed that bulk decay increases exponentially with temperature, indicating that higher temperatures accelerate chlorine degradation.

The wall decay coefficient (K_w) was estimated through literature reviews and root mean square error (RMSE) optimization, comparing simulated and field-measured chlorine concentrations. The wall decay coefficient in the Chibata district was identified as 0.020 m/day.

Using these decay coefficients, chlorine concentrations were simulated in EPANET 2.2, incorporating hourly consumption data from smart water meters. The simulation allowed for hourly estimation of chlorine concentrations at different points in the water distribution network, identifying nodes where chlorine concentrations fell below standard levels. EPANET 2.2 simulations from September 3rd to 5th, 2023, confirmed that chlorine decay rates increased during summer, with higher temperatures accelerating depletion. The simulation identified five points where residual chlorine concentrations dropped below 0.2 mg/L. These points were predominantly located at network endpoints or low-flow areas, where prolonged retention times accelerated chlorine decay. Among these, one point recorded chlorine concentrations below 0.1 mg/L for three consecutive days, indicating a persistent risk. The results confirmed that low-demand areas and network endpoints experienced the greatest chlorine depletion, emphasizing the need for targeted interventions to maintain effective disinfection.

Using smart water meter water consumption data, these points can be estimated hourly to overcome the disadvantage of conventional bimonthly meter reading, which do not allow us to grasp water consumption and water travel time daily or hourly. Hourly estimation is useful for managing residual chlorine concentration during water distribution. Consequently, early actions can be taken to maintain the chlorine concentration to ensure disinfection efficacy throughout the distribution network.

The findings of this study highlight the importance of integrating smart water metering technology with simulation-based monitoring to enhance water distribution efficiency and water quality management. By incorporating hourly consumption data into chlorine decay modeling, this approach provides a more accurate framework for predicting water quality fluctuations, optimizing chlorine dosing, and ensuring regulatory compliance.