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Public health improvements and mortality in early twentieth-century Japan

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Abstract

Taking advantage of historical documents that report detailed information about the waterworks in small to large cities in Japan, this study reveals that the popularization of tap water accounts for 27%, 31%, and 14% of the decrease in the crude death rate, typhoid death rate, and infant mortality rate between 1922 and 1940. Cost-benefit calculations estimate the average social rate of return on waterworks as 4,476%. We found that the impact of water-supply systems did *not* depend on the scale of city. This new finding supports the general finding of improvements to mortality rates due to waterworks in previous studies focused only on large / major cities, and shows its robustness for smaller cities. Our findings also support results from prior studies stressing the importance of public health interventions in explaining the decline in mortality rates.

Keywords: Mortality rate; Modern water-supply system; Piped water; Public health;

JEL Codes: I18; N30; N35;

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1 Introduction

The global burden of waterborne infectious diseases remains considerable. For instance, typhoid fever caused 22 million illnesses and 216 thousand deaths worldwide in 2000 (Crump et al. 2004; Wain et al. 2015). Public health improvements greatly impact the economy through its effect on human capital accumulation (Schultz 2010). Therefore, populations still need efficient water-supply facility planning to mitigate the risk of infection from waterborne diseases in developing countries (e.g., Banerjee and Duflo 2007).

In the United States, the impact of modern water-supply systems has gathered wider attention. Similar to European countries, the United States experienced a decline in mortality rates from the end of the 19th century to the early 20th century. Cutler and Miller (2005) point out that crude mortality rates dropped from about 18 to about 11 between 1900 and 1940 and the average life expectancy at the time of birth increased from 47 to 63 years during this period. By analyzing the panel data of 13 large major cities from 1900 to 1936, they found that approximately one-half of the decline in mortality rates, three-fourths of the decline in infant mortality rates, and two-thirds of the decline in child mortality rates are attributable to increased access to clean water. Ferrie and Troesken (2008) also investigate the decline in mortality rates in Chicago during 1850–1925. While the crude death rate fell by 60% during this period, 30–50% of this decline was due to water purification measures and the subsequent eradication of diarrheal disease, typhoid fever, and their sequella. More recently, Beach et al. (2016) found that eliminating early-life exposure to typhoid fever increased later-life earnings by one percent and educational attainment by one month. This finding newly reveals that the benefits of the clean water via water-supply systems is larger than the evidence considered earlier.

While a growing body of literature shows the mitigating effects of modern water-supply systems in large cities in the twentieth century, the effects of clean water on the mortality rates in middle- and small-scale cities is widely neglected. In fact, prior studies focused on major cities with populations above 100,000 and assumed that the effect of water-supply systems was constant across or within cities (Cutler and Miller 2005; Ferrie and Troesken 2008). [1] Thus, it is still unclear whether modern water-supply systems

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[1] The recent literature examining the importance of sewers in complementing waterworks to limit the mortality rate also focus on Massachusetts and Paris, which are major cities (see Alsan and Goldin 2015; Kesztenbaum and Rosenthal 2016).

helped to mitigate mortality rates in medium and small cities and how the magnitude of the effects of the systems on mortality rates varies with the scale of city. To bridge this gap in the literature, we compiled unique long-run panel data covering 108 small- to large-scale cities between 1922 and 1940 in Japan.

We found that the popularization of tap water, i.e., the increasing use of tap water among citizens, played a considerable role in mitigating the mortality rate, even considering medium- and small-scale cities with populations above 20,000. Our baseline estimation results reveal that modern water-supply systems installed in the greater part of Japan's cities account for approximately 27.1% of the decrease in the crude death rate, 30.6% of the decrease in the typhoid death rate, and 13.7% of the decrease in the infant mortality rate between 1922 and 1940. A cost–benefit analysis shows that the average annual benefits of modern water-supply systems are approximately 4.546 billion dollars per city and the average value of the social rate of return is approximately 4,476 %. We found that the effect of water-supply systems did *not* depend on the scale of city. This novel result now suggests that the general findings that waterworks improve mortality rates from previous studies focusing on major cities is robust.

This article contributes to the literature as follows. First, our results contribute to support evidence provided in previous studies, which stress the importance of public health interventions in the form of the health insurance system, modern waterworks, or programs that increase healthcare utilization (e.g., Szreter 1988; Bowblis 2010; Cutler and Miller 2005; Bleakley 2007; Moehling and Thomasson 2014; Gruber et al., 2014). This conclusion adds to the debate about the contribution of improvements in nutrition during the historical decline in the mortality rate (e.g., Fogel 1997, 2004; McKeown 1976, 1979; Nunn and Qian 2011). Second, our empirical evidence supports the recent results in development economics on the effects of the diffusion of piped water and the quality of drinking water, and adds to the debate about regulation policies (e.g., Gamper-Rabindran et al., 2010; Greenstone and Hanna 2014). Third, this paper also complements the literature on the benefit of waterworks in Asia, where the incidence rate of waterborne infectious diseases is currently highly concentrated (Siddiqui et al., 2006), since previous studies mainly focused on waterworks in Western countries.

The rest of the paper is organized as follows. Section 2 overviews the transition and composition of the mortality rate in the target periods and provides the historical background of the modern water-supply system. Section 3 describes the data used in the analysis. Section 4 shows the estimation strategy and provides the main results. Section 5 reports additional robustness checks. Section 6 provides cost benefit analysis. Finally, Section 7 concludes.

2 Background

2.1 Mortality rate

Although Japan continued to exhibit a relatively high mortality rate in the early 20th century in contrast with Europe and the United States, the mortality rates in Japan declined rapidly from the early 1920s. The crude death rate, defined as the number of deaths per 1,000 people, dropped from 25.4 in 1920 to 16.5 in 1940. The infant mortality rate, defined as the number of infant deaths per 1,000 live births, dropped from 165.7 in 1920 to 90 in 1940. In major cities, the crude death rate declined from 24 in 1920 to 13.4 in 1940, whereas the infant mortality rate declined from 176.6 in 1920 to 70 in 1940. The mortality rates of both respiratory and gastrointestinal infections also declined during the 1920s and 1930s. However, the most important feature in this trend is that only the proportion of deaths from gastrointestinal infections declined throughout the periods, while the proportion of deaths from respiratory infections stagnated. [2]

Figure 1a shows the number of deaths attributed respiratory infectious diseases per 1,000 deaths for the period 1921–1938 for the major cities and the other areas. Clearly, the proportion of deaths due to respiratory infections did not decrease throughout the period. In addition, the number of deaths due to respiratory infections in major cities was larger than that of the other areas. This obvious difference in the infection rates arose mainly from the difference in the infection risk of tuberculosis between urban and rural areas. [3] This disparity is associated with the fact that people in urban areas were more likely to be exposed to the risk of infectious disease (Kawakami 1982, pp.332–340). Although the tuberculosis mortality rate in England and United States was on a decreasing trend in the

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[2] The time-series plots of the crude death rate, infant mortality rate, respiratory death rate, and gastrointestinal death rate are shown in Figures G.1, G.2, and G.3 in Appendix G, respectively. Please note that Japan experienced the aforementioned decline in the urban mortality rate *before* the introduction of a comprehensive sickness insurance system (*Kokumin kenkohoken ho*) in 1958. See Ogasawara and Kobayashi (2015) for the discussion.

[3] See Table G.1 and Table G.3 in Appendix G for the details.

same period, Japan had not prevented the spread of tuberculosis and other respiratory infectious diseases in the 1920s and 1930s (see Kawakami 1982, pp.335–336).

By contrast, Figure 1b shows that the number of deaths attributed gastrointestinal infectious diseases per 1,000 deaths declined rapidly from the mid-1920s in major cities. This steady decline is related to the improvement of the risk of death due to the major waterborne infectious diseases: diarrhea, enteritis, and typhoid fever. This remarkable decline in deaths from gastrointestinal infectious diseases in urban areas was also observed in infant mortality. [4] Since the modern water-supply system was installed in a lot of cities during 1920s and 1930s Japan, the abovementioned fact strongly suggests that the improvement of the quality of drinking water mitigated the risk of death associated with waterborne infectious diseases in urban areas.

2.2 Development of water-supply systems in prewar Japan

In this subsection, we outline the old and modern water-supply systems in prewar Japan. Then, we explain the uncertainties of the modern water-supply projects as well as the quality of the modern water-supply systems. Throughout this subsection, we use the compilation of historical material, namely, the *History of Water Supply System in Japan (Nihon suido shi)* as a main historical document. It was edited by the Japan Water Works Association and consists of five volumes, exceeding 4,000 pages in total. Undoubtedly, this document is the most comprehensive compilation of historical material of Japan's water-supply systems.

2.2.1 Old water-supply system

Waterworks prior to the installation of modern water-supply systems relied on the natural downward flows of rivers and springs, which were directed to urban areas. These unsophisticated facilities supplied raw water for drinking purposes, without any filtration for purification, and consequently, achieved only very low standards of hygiene. These systems did not utilize water pressure to supply water, and hence, were inadequate for the purposes of firefighting (Japan Water Works Association 1967a, p.63).

For instance, water-supply projects in Tokyo began in the Edo (premodern Tokyo) period. Edo was built on marshy land with many swamps, with salt encroaching from the

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[4] See Table G.2 and Table G.4 as well as Figure G.4 in Appendix G for the details.

nearby ocean. In order to secure the city's supply of potable water, the first shogun, Ieyasu Tokugawa, carried out a study of the water supply in 1590 and ordered the construction of the Koishikawa channel (*josui*), which utilized natural river water. Subsequently, the aqueduct of the Tamagawa channel was constructed in 1654 in response to urban development. The water-supply system within the city was constructed by stone channels (*sekihi*) or wooden pipes (*mokuhi*) and bamboo water pipes that branched out from these (*yobihi*) (see Bureau of Waterworks Tokyo Metropolitan Government 1999a, pp.1–5).

By the time of the establishment of the Meiji Government at the end of the 19th century, the quality of water within the Edo-era system had diminished drastically due to pollution of the waterways and deterioration of wooden pipes. A survey conducted around 1880 by the University of Tokyo and the Sanitary Bureau of the Home Department found that water in city was even likened to "thinned urine" (see Bureau of Waterworks Tokyo Metropolitan Government 1999a, pp.6–7). Some waterways constructed in domains outside of Edo also employed similar methods to transport water, mainly to wells, and likewise, did not involve any filtration. Thus, the introduction of these waterworks were not able to contribute to lowering the risk of infection from waterborne infectious diseases.

2.2.2 Modern water-supply systems

The Japanese government prioritized the installation of a modern water-supply system in the city of Yokohama, one of the open ports under commercial treaties and a site of arrival for foreigners. In 1887, Yokohama became the first city in Japan to introduce a modern system in which water was purified at a filtration plant and delivered via steel pipes. [5] Hakodate and Nagasaki city were open ports and hence, began construction on water-supply systems at a comparatively early stage, in June and April 1888, respectively.

The Waterworks Ordinance established in 1890 provided for the construction of waterworks using public funds from cities, towns, and villages with the authorization of the Home Minister. The ordinance also outlined methods of construction management. Nonetheless, by the end of the 19th century, modern water-supply systems had been introduced only in the most highly populated cities and open ports, and the portion of the population able to enjoy these systems remained small as shown in Figure 2. [6]

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[5] The photograph of wooden pipe (*mokuhi*) and cast–iron pipes (*chutetsukan*) are shown in Figure H.1 and Figure H.2–H.4 in Appendix H.

[6] See Section A.1 in Appendix A for the background and detailed contents of the Waterworks Ordi-

The construction of modern water-supply systems in small and medium-sized Japanese cities gathered pace only during the interwar period. In 1918, the national government committed to subsidizing the construction of systems at the town and village levels. The scope of the subsidy was expanded in 1921 to include not only city but also town and village operations. [7] Figure 2a shows many modern water supply systems were installed between the early 1920s until the weakening of Japan's wartime regime in 1940. In 1921, modern water-supply systems had been installed in 55 locations and water was piped to 18% of the population. By 1940, these figures had increased to 345 locations and 34.4% of the population, respectively. [8] At the same time, the maximum average amount of potable water per person per day was 0.023 cubic meters in 1921, increasing to 0.061 cubic meters in 1940. Figure 2b shows these developments in the modern water-supply systems.

In summary, the introduction of modern water systems began in earnest from the early 1920s, and this was followed by a gradual increase in water consumption. This trend is consistent with the previously indicated decline in the proportion of deaths from waterborne infectious diseases occurring in the same period. Accordingly, this paper hypothesizes that the popularization of tap water, that is the diffusion of clean water among citizens, played an important role in decreasing the mortality rate in urban areas from the 1920s to the 1930s.

2.2.3 Uncertainties of modern water-supply projects

We argue that not only the variation in the timing of installation but also the transition of the coverage of water taps per capita were affected by both the geographical factors of the cities and unpredictable events, such as natural disasters, water politics, and economic fluctuations. For this purpose, we investigate the histories of modern water-supply systems in all cities that are used in our empirical analysis. Table 1 shows exemplary factors that decided the installation of water-supply systems, typical unpredictable events that affected

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nance.

[7] Section A.4 in Appendix A describes the details and an example of the government subsidies. For more information on how funds for waterworks projects were managed, see Section A.3 in Appendix A.

[8] The supplied population is the number of people in an area or region to which water is delivered, and is an estimated proportion of the population that utilizes waterworks. Because this value also includes people without access to a tap connected to water pipes, it tends to overestimate the rate of waterworks distribution.

the timing of installations, and representative uncertainties that influenced the pace of the water-supply works in the cities that implemented the systems during the 1920s and 1930s. [9]

First, the main factor behind the installation of modern water-supply systems was not the epidemic of infectious diseases but geographical factors and natural disasters. For instance, as described in Table 1, Sendai was blessed with neither quality nor quantity of groundwater. In addition, Nishinomiya was not endowed with good quality and quantity of well water. Although a small number of cities, such as Sapporo, Morioka, and Fukushima, experienced deterioration of drinking-water sources due to nongeographical factors, such as population growth or industrial development, almost all cities have the same natural geographical features. In addition to the geographical reasons, some natural disasters, such as droughts, floods, and big fires, played a significant role in implementing the modern water-supply systems. For example, Morioka, Sendai, Taira, Fukuoka, and Kagoshima experienced fires before installing the system. Furthermore, Yokosuka listed the wars as a secondary factor. Since Yokosuka has a large navy base, the outbreak of the war forced the navy to install a system.

Second, the process of installation works was also influenced by natural disasters, outbreak of the wars, economic fluctuations, and political issues. The sixth column in Table 1 lists those uncertainties in the installation works in each city. As for the factors of installation, the process of installation works depended largely on the outbreak of natural disasters and of the wars; Sendai, Yamagata, Taira, Yokosuka, Nagaoka, Takata, Matsue, Tokushima, Takamatsu, Fukuoka, Nakatsu, and Kagoshima experienced these shocks during the installation works. Natural disasters caused the destruction of water-supply facilities under construction, and often destroyed important administrative documents of the laying plans. Rising prices of construction materials, such as metal water pipes due to the outbreak of the wars, postponed the completion of the installation works in many cities. In addition, some cities delayed their laying plans due to the shortage of financial sources or increasing prices of construction materials and labor costs for reasons other than natural disasters. One example is the effect on construction plans due to fluctuating

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[9] For the purpose of brevity, we list the cities that implemented modern water-supply systems before the interwar period in Table G.5 in Appendix G. As we confirm in both tables, we can argue that they had similar reasons for installation and experienced similar typical uncertainties in the process of the expansion works, regardless of differences in the timing of installation.

prices of cast-iron pipes used to supply water. As the iron industry relied partially on foreign imports for primary materials, economic conditions and the outbreak of war had a large impact on the production and prices of iron and steel (Japan Water Works Association 1967a, pp.657–658). This fact strongly suggests that the timing of completion was affected by economic fluctuations.

City-specific and geographical features occasionally affected the implementation of the laying plans. Morioka, Yokosuka, and Yokkaichi cities eventually were able to use existing water-supply systems as part of their modern water-supply systems. Since Takamatsu city is located at the north-western part of the island of Shikoku, which is in southwest Japan, and faces the Seto Inland Sea, the city has a warm climate and light rainfall. In addition, the basins of the rivers around Takamatsu city are shallow and thus, the city had long been plagued by difficulties in finding a water source (see Japan Water Works Association 1967d, p.362).

Furthermore, political issues were obvious uncertainties in the process of installation works; for example, water rights, residents' opposition to laying plans, delayed land acquisition, and conflict between city diets, leading to rejection of laying plans in the councils. Almost all the political issues were closely tied to disputes over water rights. Sapporo city spent a long time acquiring water rights due to the conflict between a paper company and an electric power company (Japan Water Works Association 1967b, p.1). In addition, other cities, such as Fukushima, Himeji, Nishinomiya, Tokushima, and Fukuoka, postponed laying plans because farmers or irrigation associations opposed laying a modern piped-water system. As many modern Japanese water-supply systems relied on the use of surface flows, "the management of water rights has been the cause of headaches for interested parties throughout every age, and often obstructed the construction of waterworks" (Japan Water Works Association 1967a, p.591). As a results, as listed in the second to fourth columns of Table 1, most cities took considerable time to commence modern water-supply systems after laying plans started.

Third, the expansion of the number of water taps was also influenced by natural disasters, outbreak of the wars, economic fluctuations, and political issues. The final column in Table 1 lists those uncertainties in the expansion of the water taps in each city. Clearly, almost all the expansion projects were influenced by the incidence of natural disasters and the outbreak of the wars. Changes in the natural state of water sources accelerated or decelerated the accomplishment of expansion projects. For example, although Takamatsu city experienced an unexpected decline in pumping discharge and thus, could not expand the population supplied in the early stage, the city succeeded in finding a subwater source to improve its pumping discharge ability in 1927 (see Japan Water Works Association 1967d, p.358). Other cities, such as Yamagata, Ueda, Tokushima, and Nakatsu, also experienced this kind of state change. In addition, the deterioration of water-supply systems itself influenced the project in a few cities.

Like the process of the installation works, economic fluctuations affected the process of expansion projects; Morioka, Taira, and Himeji cities recorded that declines in the prices of materials or demand for water usage by companies influenced their expansion projects. Political issues or consolidation of municipalities also influenced the projects in some cities, such as Taira, Himeji, Nishinomiya, Nakatsu, and Kagoshima. As a rule, while confrontation between political parties tended to postpone important decisions related to the expansion projects, consultation of municipalities was more likely to force cities to improve water-supply capacity in order to cover the population residing in the integrated areas.

Foregoing historical facts reveal that not merely the variation in the timing of installation but as well the improvement of the coverage of tap water were affected by the geographical factors of the cities and unpredictable events, such as natural disasters, water politics, economic fluctuations, and wars.

2.2.4 Quality of tap water

We next consider the quality of water supplied by the modern water-supply systems. The filtration facilities are the most important piece of technology in the purification process. This technology involved passing water through layers of sand, thereby removing impurities and bacteria, including pathogens, by the action of a membrane of micro-organisms that forms on the surface of the sand layers. The slow-speed filtration technology, which was able to purify around 3 meters of water in 1 day, formed the cornerstone of water purification throughout 1920s and 1930s of Japan. [10]

Records of water-quality tests carried out by each city indicate that the quality of tap water was sufficiently high. In March 1904, cities with modern water-supply systems

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[10] See Section A.5 in Appendix A for more details of the water purification technologies at that time.

organized a “Conference for Standardized Waterworks Testing” to establish an agreed set of testing methods for waterworks and decided to carry out water-quality testing using these methods. The testing methods were divided into sampling methods, chemical testing methods, bacteriological testing methods, and methods for judging the suitability of water for consumption. [11] Of these testing methods, bacteriological testing is the most important test of water quality. Bacteriological testing was carried out to ensure that colony forming units (CFU) of bacteria were kept to below 100 CFU/ml of water at the tap point. This threshold figure was arrived at by Robert Koch, known as the founder of modern microbiology, who had determined that cholera and typhoid would not occur in piped water that had been filtered via slow filtration to below this level (see Exner et al., 2003, p.13). The threshold of 100 CFU/ml continued to be used after the Second World War (e.g., Ichikawa 1990). Accordingly, CFU is a reliable indicator for assessing levels of water quality for the period of interest in the present study.

Table 2 shows the number of bacterial colonies obtained from the bacteriological inspections at source water or water taps in the cities. Clearly, filtration technology significantly reduces the number of bacterial colonies and thus, improves the quality of drinking water in the cities. Overall, the number of bacterial colonies decreased from 468.9 CFU/ml to 14.2 CFU/ml, which is below the criterion value, 100 CFU/ml. Even if we split the sample periods into small groups, filtration technology played a significant role in mitigating the number of bacterial colonies in drinking water.

Foregoing result suggests that the quality of water provided through the modern water-supply system in interwar Japan have passed contemporary bacteriological testing standards. As a result, water quality at the time reached levels that led to a reduction in the risk of infection by waterborne infectious diseases.

3 Data

Sample characteristics

The present study uses panel data of 108 cities each with populations above 20,000 people between 1922 and 1940. As discussed in Introduction, an important contribution of this

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[11] A detailed list of test items was specified for each of these methods. See Table G.6 in Appendix G for more details.

study is that we focus on the effects of modern water-supply systems not only in major cities but also in small- and mid-scale cities that were widely ignored in the previous literatures. Among all cities between 1922 to 1940, our sample cities share approximately 91% of total city population. Figure 3 describes the geographical distribution of our sample cities. Clearly, the cities are distributed throughout the whole country and are not concentrated in a specific area. This spatial distraction of the cities suggests that heterogeneity of city characteristics is ensured in our sample.

Coverage of tap water

This study tests whether the popularization of clean tap water, i.e., the increase in the number of water taps relative to the number of citizens, in a city decreased mortality rates due to preventing the infection of waterborne diseases.

To achieve this purpose, we first compiled data on the number of water taps in each city from the statistical reports published by the Federation of Water Authorities and the Water Works Association between 1922 and 1943; *Statistics and Reports of Water Supply* (SRWS) (vol.1–21) and *Statistics of Water Supply* (SWS) (vol.22–31). The coverage of tap water (*Water*) is then defined as the number of water taps divided by 100 people. Thus, a larger coverage of tap water means that more citizens are able to access clean water. The plentiful within-variations in the coverage of tap water enable us to identify the effect of modern water-supply systems on mortality rates as described in Subsection 2.2.3. Finer details of the historical documents used are described in Appendix B.

Almost all cities introduced filtration technology at the time of installing their modern water-supply systems. However, a few cities that installed modern water-supply systems used settling ponds, flocculants, and metal pipes, and did not introduce a specific slow or rapid filtration system. Therefore, we further analyze the pure effect of filtration technology on the mortality rate by using the coverage of filtered tap water (*Filtered water*) as a sensitivity check of variable definition. This alternative measurement of quality and popularization of tap water is defined as the number of water taps through one or both slow and rapid filtration systems per 100 people. We find that the improving effect of tap water is estimated to be larger when we use the coverage of filtered tap water as a measure of the popularization of tap water (see Subsection 5.2). Panel (c) in Table 3 reports the summary statistics of variables of interest.

Measures of mortality rates

We use the crude death rate, typhoid death rate, and infant mortality rate as our primary measures. The crude death rate is employed in our empirical analysis as the main measurement of mortality rates. Following the regular definition, we define the crude death rate as the number of deaths per 1,000 people. The typhoid death rate is the number of deaths due to typhoid fever per 1,000 people. This measure is used as the main measurement of the risk of water-related deaths. Although the information on infant deaths is limited compared to the other two mortality measures, the infant mortality rate, defined as the number of infant deaths per 1,000 live births, is also used in our analysis. Since all the information on the number of deaths listed above are constructed using official statistics after the first national census in Japan, these statistics are known to be sufficiently accurate (Ito 1987).

Furthermore, we use the cause-specific death rates in order to capture the effect of water-supply systems more precisely. While clean water may have improved the risk of waterborne infectious diseases directly, respiratory infectious diseases are less likely to be affected by improvement of water quality. Therefore, we expect the effects of waterworks are estimated to be negligible on the respiratory infectious death rate but these effects cannot be ignored for the gastrointestinal infectious death rate. We are able to compile the number of cause-specific deaths for 26 cities with populations of more than 100,000 from 1922 to 1936 using several historical documents. The deaths from respiratory infections can be decomposed into deaths from measles, scarlet fever, whooping cough, diphtheria, influenza, tuberculosis, bronchitis, and pneumonia. Gastrointestinal infectious deaths include deaths from typhoid fever, dysentery, and diarrhea. Panel (a) and (b) in Table 3 reports the summary statistics of the mortality rates.

Control variables

We use covariates representing the demographic and socioeconomic characteristics of the cities as the baseline controls in our empirical analysis. For demographic variables, we use the natural logarithm of total population and shares of various age groups. The shares of the population aged 0–14, 15–24, 25–59, and 60+ years are calculated as the number of people in each age group divided by total population in percentage points. For the socioeconomic controls, we consider the size of financial budget, opportunities for medical treatment, and share of industrial workers in the total population in each city. These factors are measured by the natural logarithm of city's total annual revenue per capita, number of doctors per 1,000 people, and proportion of factory workers per 100 people, respectively. Among them, the coverage of doctors and proportion of factory workers are measured at prefectural level.

In the robustness checks, we further include additional demographic and meteorological controls. Additional demographic variables are the sex ratio of the population aged 0–14, 15–24, 25–59, and 60+ years. These variables control for the influence of the shorter lifespans of men than for women at that time (e.g., Statistics Bureau of the Cabinet 1936; Johansson 1996; Regan and Partridge 2013). For the meteorological variables, we collect both monthly average of the annual temperature, total amount of annual precipitation, average monthly humidity, and average monthly actual sunshine duration from the database of the Japan Meteorological Agency (JMA). These variables are included because the demand for water depends on the external environment, such as temperature and sunshine duration where people live (see, World Health Organization 2003, pp.6–7). In addition, waterborne diseases themselves are more likely to depend on the spatial heterogeneity of climate, such as annual precipitation (e.g., Ni et al., 2014). The summary statistics of all control variables are reported in Table G.7 of Appendix G.

4 Econometric strategy and main results

4.1 Baseline model

We use the heterogeneity in the coverage of tap water to analyze in detail the impact of modern water-supply systems on mortality rates. Hence, we employ the following city fixed-effects approach as our identification strategy. [12] A city's mortality equation is

$$y_{it} = \alpha + \delta\, Water_{it} + \mathbf{x}'_{it}\boldsymbol{\beta} + \sum_{c=2}^{108} \gamma_c I_{ci} + \sum_{j=1923}^{1940} \rho_j I_{jt} + t \sum_{c=2}^{108} \mu_c I_{ci} + e_{it} \tag{1}$$

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[12] Appendix C contains a descriptive analysis for a few representative examples.

where i indexes cities from 1 to 108 and t indexes years from 1922 to 1940. The variable y_{it} is either the crude death rate, typhoid death rate, or infant death rate, $Water_{it}$ is the coverage of tap water, $\mathbf{x}'_{it}$ is a vector of city characteristics, and e_{it} is a random error term. I_{ci} and I_{jt} are the indicator variables that equal one for the city c and year j, respectively. The variables $\sum_{c=2}^{108} I_{ci}$ and $\sum_{j=1923}^{1940} I_{jt}$ represent city and year fixed effects, respectively. The coefficient δ is our parameter of interest and its estimate $\hat{\delta}$ measures the impact of the popularization of tap water on each mortality rate. [13]

In our fixed-effects approach, identification depends on the time variation within the same city owing to the popularization of water taps. Hence, our identification assumption is that, conditional on city observables, the coverage of tap water by each city is exogenous. In Subsection 2.2.3, we argue that this assumption is plausible. To summarize the reasons, not only the timing of installation but also the diffusion of water taps depends on large random components, such as natural disasters, economic fluctuations, and political issues. Thus, the coverage of tap water should be determined exogenously after controlling for the proper covariates. Although the rate of tap water dissemination may be correlated with cities' wealth levels, we can consistently estimate the parameters of interest after conditioning on both observable wealth levels, such as the number of citizens or total revenue per capita. In addition, any other time-invariant determinants of the city's regulatory capacity, such as a city's attitude toward public health or the geographical features that affected the timing of installation of modern water-supply systems, continue to be controlled by employing a city fixed-effects approach.

We should mention further possibilities in our model. First, we relax the common trend assumption in the fixed-effects model. The crude death rates in almost all our sample cities show similar decreasing trends during our sample periods. However, we should further relax an assumption in our model, that is, the common mortality trends across cities, since it is realistic to assume that more than 100 cities should not have a strictly common trend in mortality rates. We cope with such differences in trends as much as possible by adding the interaction term between city fixed effects and the linear time trend, $t\sum_{c=2}^{108} I_{ci}$ in equation (1). Second, we estimate flexible specification by replacing the covariates with the covariates multiplied by the period dummy. Then, our flexible

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[13] We focus on the aspect of water quality rather than water quantity, i.e., water consumption per capita. We confirmed that improvements in daily water consumption per capita had no significant effects on mortality rates. See Appendix D for a detailed discussion.

specification of the baseline model is given by

$$y_{it} = \alpha + \delta \, Water_{it} + \mathbf{x}'_{it} \boldsymbol{I}_t^{1930s} \boldsymbol{\beta}_j + \sum_{c=2}^{108} \gamma_c I_{ci} + \sum_{j=1923}^{1940} \rho_j I_{jt} + t \sum_{c=2}^{108} \mu_c I_{ci} + e_{it} \qquad (2)$$

where I_t^{1930s} is an indicator variable that equals one for the period from 1931 to 1940, and the other variables are defined as in equation (1). This specification allows the coefficients of all control variables to vary across periods. Finally, in order to deal with heteroskedasticity and serial correlation in the idiosyncratic error term raised from the nature of relatively long panel data, we further employ cluster-robust standard errors (Stock and Watson 2008). Standard errors are clustered at the city level. [14]

Table 4 shows the main results of our baseline model. Columns (1)–(4), (5)–(8), and (9)–(12) report estimates for the crude death rate, typhoid death rate, and infant mortality rate, respectively. Estimates of equation (1) are reported in columns (1)–(2), (5)–(6), and (9)–(10), while estimates of equation (2) correspond to columns (3)–(4), (7)–(8), and (11)–(12). In columns (1), (3), (5), (7), (9), and (11), we include baseline demographic controls, such as the natural logarithm of the total population, and the shares of various age groups. The results in columns (2), (4), (6), (8), (10), and (12) report estimates for our baseline specification. In this specification, we also control for socioeconomic controls, such as the number of doctors per 100 people, proportion of factory workers per 100 people, and natural logarithm of total revenue to address accessibility to medical facilities, level of industry development, and fiscal scale of local governments, which might be correlated with the coverage of tap water congenitally. We include city and year fixed effects in all specifications and thus, any unobserved city and time effects that might have affected the progress of water-supply systems, such as geological and geographical features, cities' preferences for public health investments, macroeconomic shocks, and countrywide epidemic of infectious diseases, are controlled. In addition, we control for city-specific time trends by including the interactions of city fixed effects and a linear time trend in order to allow the estimates to take into account differences in the mortality trends across cities.

Clearly, the estimates are stable across different specifications. [15] The estimated

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[14] As for the spatial correlations, our baseline estimates are robust to clustering standard errors at the prefectural level. See Table G.8 in Appendix G for the results.

[15] We also estimated the dynamic panel data model for all mortality rates to deal with a mean-reverting

coefficient on *Water* is negative and statistically significant in all death rates. Columns (1), (5), and (9) of Table 4 show that a 1% increase in the coverage of tap water decreased the crude mortality rate, typhoid death rate, and infant mortality rate by 0.165, 0.008, and 1.072, respectively. In addition, the results are robust to controlling for the variations in socioeconomic status in the cities. When we allow the coefficients of all controls to vary across periods, these effects remain 0.166, 0.008, and 1.268, respectively (from columns (3), (7), and (11), respectively).

Our baseline estimates are listed in columns (4), (8), and (12). This result shows that, on average, a 1% increase in the coverage of tap water decreased the crude mortality rate, typhoid death rate, and infant mortality rate by 0.166, 0.009, and 1.216, respectively. The median of the coverage of tap water across our sample cities increased by 7.63%, from 0% in 1922 to 7.63% in 1940. [16] Based on our baseline estimates, the modern water-supply system contributed to improve 1.27, 0.07, and 9.28 per thousand of the crude death rate, typhoid death rate, and infant mortality rate, respectively. Therefore, the increased availability of clean water accounts for approximately 27.13% of the drop in the crude death rate from 21.62 to 16.95, approximately 30.62% of the drop in the typhoid death rate from 0.37 to 0.14, and approximately 13.67% of the drop in the infant mortality rate from 168.97 to 101.93 between the beginning of the 1920s and the end of the 1930s. [17] Thus, our result suggests that roughly 3 out of 10 improvements of the crude and typhoid death rates are associated with the popularization of the modern water-supply system in Japan's cities during the 1920s and 1930s.

To clarify the standing of our results, we discuss the estimated effects of the waterworks by comparing the results to the previous study. In the case of the major cities in the United States between 1900 and 1936, the contribution of the installation of clean-water technology is estimated to be somewhat larger than that of Japan's; about 43% of the changes in the crude death rate in the United States was associated with the installation of the filtration and chlorination technologies (Cutler and Miller 2005, p.13). We expect

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process, that is the possibilities that the access to water expands rapidly in years folioing unusually severe outbreaks of infectious diseases. Our baseline estimates are robust to including lagged dependent variables as shown in Table G.9 in Appendix G.

[16] In order to take the large disparity in the coverage of tap water between small and large cities, such as Tokyo and Osaka, we should use median value here rather than mean value.

[17] In order to deal with the annual fluctuations of each mortality rate, we use the 3-year average from 1922 to 1924 as a starting point, and the 3-year average from 1938 to 1940 as an end point of the calculation. Appendix E reports the detailed interpretation of the results for infant mortality rate.

that a large part of this disparity may arise from the difference in the scale between cities. While the United States sample includes 13 large major cities with populations of more than 100,000, our data consists of 108 small- to large-scale cities with populations of more than 20,000. The total mortality change in the major cities of the United States was 30% in the crude death rate, 96% in the typhoid death rate, and 62% in the infant mortality rate, while the corresponding changes in our sample were 21.6%, 61.2%, and 39.7%, respectively. These differences imply that the contribution of modern water-supply systems to improved mortality rates may vary by scale. Thus, we test the heterogenous effects with respect to city size using a flexible specification of our baseline models in the next subsection.

4.2 Testing heterogeneous effects with respect to city size

The field of epidemiology has examined the relationship between the scale of population and incidence of waterborne diseases (e.g., Karkey et al., 2010; Dewan et al., 2013). The findings imply that the effects of modern water-supply systems might depend on the scale of city. Previous studies investigating the effect of water-supply systems on the mortality rate are, however, less likely to have considered the heterogeneous effects with respect to city size and have therefore assumed that the effects of water-supply systems were constant across cities. To bridge this gap in literature, we investigate whether the effects of modern water-supply systems may depend on the scale of cities.

Taking advantage of our comprehensive dataset, which includes small to large cities, we consider the interaction terms between the coverage of tap water and natural logarithms of city population ($Population_{it}$). In our polynomial specification, we also include the interaction term between the tap water coverage and the squared term of $Population_{it}$ to capture the nonlinear relationships. If the effect of clean water depends on city size, the coefficients on the interaction terms should be significantly positive or negative. We also estimate a flexible specification in which we replace the covariates with covariates that multiply the period dummy, which is the same as our baseline model.

Table 5 presents the results of our flexible model. We include baseline controls in columns (1), (4), and (7), and report the flexible specification in columns (2), (5), and (8), including the baseline controls with the period dummy. The results in columns (3), (6), and (9) report estimates for our preferred specification. In this specification, we also control the interaction term between the tap water coverage and the quadratic term. All specifications include the city and year fixed effects and city-specific time trends.

As shown in columns (1), (4), and (7), the estimated coefficient on the interaction term tends to be negative, but has no significant impact on mortality rates. The results are robust when allowing the coefficients to vary across periods ((2), (5), and (8)) and for nonlinear relationships ((3), (6), and (9)). These results confirm that the effect of tap water coverage did not depend on or vary with the scale of city. This result does not change across all specifications, which are reported later in this paper (see also Table G.12 and G.13 in Appendix G for alternative specifications).

Our estimates imply that the effects of water-supply systems on mortality rates might have been similar across cities, even if we include both small and major cities in the analytical samples. The insignificant effect of city size is indeed consistent with findings in recent epidemiological studies, which argue that the incidence rates of waterborne diseases are not related to population size or urban/rural locations (e.g., Karkey et al.2010; Dewan 2013). Our results are very significant because it supports the robustness of the findings in the previous studies, which have assumed invariant effects of clean water across cities and/or within a city (e.g., Cutler and Miller 2005; Ferrie and Troesken 2008). Foregoing discussion implies that the magnitudes of our baseline estimates were smaller than those of the clean-water technologies installed in the major cities of the United States between 1900 and 1936 regardless of the scale of city. We will follow up this point again in Section 6.

5 Robustness check

5.1 Additional control variables

In our baseline specification, we control for a set of demographic and socioeconomic controls as well as the interactions of these controls and a period dummy. In this section, we further consider an additional set of factors that might have affected the mortality rates as a part of the sensitivity checks.

The first set of additional controls captures factors that may not be controlled by the demographic controls in our baseline specification. Additional demographic controls include the sex ratio of the population aged 0–14, 15–24, 25–59, and 60+ years. It is known that the ratio of female to male deaths varies across time, space, and age groups (e.g., Johansson 1996). These variables control for the heterogeneity and biological differences of the shorter lifespans of men compared to women (e.g., Regan and Partridge 2013; Statistics Bureau of the Cabinet 1930). In addition, we include additional controls that capture differences in the meteorological conditions of each city. We collect both the average monthly temperature, total amount of annual precipitation, average monthly humidity, and average monthly actual sunshine duration from the database of the JMA. These meteorological covariates are included because atmospheric conditions directly or indirectly affect the risk of mortality (e.g., Allen and Sheridan 2014; Goggins et al., 2013; Jonkman 2009; Pradhan 2007). The demand for water might also depend on the external environment, such as the temperature and sunshine duration where people live (e.g., World Health Organization 2003, pp.6–7).

The estimates are reported in Table 6. Our baseline estimates reported in columns (2), (4), and (6) remain stable and are almost the same magnitudes as the baseline estimates reported in Table 4. Therefore, estimated impacts of modern water-supply systems are robust to controlling for other determinants of the mortality rates.

5.2 Sensitivity to variable definition

In our sample, most cities installed filtration technology simultaneously when they installed their facilities of modern water-supply systems, such as settling ponds, flocculants, distribution reservoirs, and cast-iron pipes. Some cities that enjoyed particularly pure raw water, however, did not install filtration ponds but rather supplied raw water directly from settling ponds. The quality of source water in those cities was indeed originally high; bacterial CFU in the source water and taps were 11.6 and 10.4 (/ml), respectively. [18] Those cities had relatively weak incentives to install the filtration technology because the quality of drinking water was naturally high as a result of the clean water source.

This implies that those cities with filtration technology experienced more drastic declines in the mortality rates than cities without such technology, as Cutler and Miller (2005) suggest. Therefore, if our hypothesis is correct and if our baseline results—that modern water-supply systems played an important role in mitigating the mortality rates—are robust, the magnitude of our estimates will be estimated to be larger when focusing

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[18] See Table G.14 in Appendix G for details of the bacterial CFU in the source water and taps in those cities.

on the effect of only filtered tap water. To assess this sensitivity of variable definition, we use the number of water taps with filtered water per 100 people (*Filtered water*) as an alternative measurement of the coverage of tap water.

Table 7 presents the estimation results. Overall, the estimates are slightly larger than those in Table 6. For instance, the estimated coefficients in columns (2), (4), and (6) in Table 7 are -0.207, -0.011, and -1.277, respectively, whereas the estimated coefficients under the baseline definition of the coverage of tap water are -0.174, -0.010, and -1.262, respectively (see columns (2), (4), and (6) in Table 6). Therefore, the impact of tap water increases when we restrict the definition of water taps to taps with filtered water. This result confirms that our key variable for the popularization of tap water in the baseline estimates captures the effect of modern water-supply systems well.

5.3 Placebo test using lead values of the coverage of tap water

The final strategy we employ as a sensitivity check is to include the leads of the coverage of tap water in years $t+1$, $t+2$, and $t+3$ in the specification reported in columns (2), (4), and (6), respectively, in Table 6. Since the lead values are the realization values in the future periods, the abovementioned specifications, including these leading variables, can be considered as a placebo experiment. When the coefficients on the leading variables are estimated to be significantly negative, the common trend assumption would be violated and/or our baseline results should be affected by some omitted variables, such as positive preference of local governments for public health investments.

The estimates are reported in Table 8. Columns (1)–(3), (4)–(6), and (7)–(9) report estimates for the crude death rate, typhoid death rate, and infant mortality rate, respectively. Both the baseline and additional control variables as well as fixed effects are included in all specifications. Clearly, the estimated coefficients on the lead variables do not differ significantly from 0 and those impacts are considerably weak in all specifications. This result implies that the parallel-trend assumption of the fixed-effects model should hold and supports the evidence that any omitted variables do not disturb our baseline estimates. Moreover, the estimated coefficients on the coverage of tap water at year t remain negative and statistically significant in most specifications. Taken together, these results confirm the finding from our baseline estimates in Table 4.

5.4 Cause-specific death rates

Finally, we use the cause-specific death rates in order to test the impacts of modern water-supply systems further. Decomposing the total deaths into cause-specific deaths helps us understand the channel through which infectious diseases were improved by the popularization of tap water. We expect that the effects of waterworks on the respiratory infectious death rates are estimated to be negligible, while the effects on the gastrointestinal infectious death rates are estimated to be significantly negative. In some sense, the results for respiratory infectious diseases can be interpreted as a placebo experiment. The sample used in the analysis is restricted to 26 cities with more than 100,000 people from 1922 to 1936 due to limited data availability.

The estimation results for cause-specific death rates are reported in Table 9. [19] As expected, the estimated coefficients for respiratory infectious death rates are occasionally negative but not significant in most cases. The estimate for scarlet fever is likely to support an aspect of the Mills–Reincke phenomenon, which emphasizes the case in which the improvements in waterworks improves not merely deaths due to waterborne diseases but also deaths from water-related diseases, including respiratory infections (see Ferrie and Troesken 2008; Sedgwick and MacNutt 1910). In fact, scarlet fever is caused by the common bacteria known as group A streptococcus (GAS), and thus, hand-washing using clean water reduces the risk of transmission of GAS (Ray 2014).

By contrast, as expected, the popularization of tap water has a significant decreasing effect on gastrointestinal infectious diseases. The estimate for the typhoid death rate is consistent with the medical evidence that shows a link between waste water and the outbreak of typhoid fever, which is caused by Salmonella enterica serovar Typhi and is transmitted by the fecal–oral route (e.g., Farooqui et al., 2009). The popularization of tap water also reduced the deaths from dysentery and diarrhea. This result is striking because these diseases comprised the greater part (more than 90%) of gastrointestinal infectious deaths at that time. [20] This is highly consistent with the epidemiological evidence that improved water quality reduces the risk of diarrhea, which is caused by various pathogens transmitted along various routes (e.g., Cairncross et al., 2010), as well

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[19] We also employed wild cluster bootstrap method proposed by Cameron et al.(2008) to deal with few clusters issue. We confirmed our main result is stable against using the wild cluster bootstrap-t procedure. Table G.10 in Appendix G shows the result.

[20] See Table G.1 in Appendix G for the proportion of deaths from dysentery and diarrhea.

as the risk of dysentery, which is caused by Shigella flexneri (e.g., Han and Hlaing 1989).

6 Social rate of returns

This study attempts to add further to the debate about the importance of the investment in public health in reducing the mortality rates in developing countries (e.g., Greenstone and Hanna 2014). To illustrate the contribution of the modern water-supply systems in prewar Japan, we prove a estimate of the social rate of return of city investments in waterworks using our baseline estimate as well as detailed information on the cost. In our estimate, we focus on the potential benefits from reduced mortality rates, though improving water-supply systems has other many benefits, such as a decline in morbidity and an increase in wages (see Beach et al. 2016, pp.69–71).

We calculate the overall benefits of modern waterworks as finely as possible under reasonable and conservative assumptions. The procedure to calculate benefits is described in detail in Appendix F. As reported in Table 10, the average overall benefits of the modern waterworks are estimated as 4,546 million dollars, and the 95% confidence intervals are [462, 8690] (see sixth row of table).

To calculate average annual cost, we compile the information both on the total cost of each laying and expansion project and on the exact date of their completion in each city from the SRWS and SWS. Following a previous study, we assume that the facilities of the modern water-supply systems could be used for only 10 years from completion (see Cutler and Miller 2005, p.18; Beach et al. 2016, p.71). [21] The average annual cost in 2014 dollars is estimated as 102 million dollars. [22]

It is estimated that the average value of the social rate of return of the modern water-supply systems is 4,476%. An important contribution of this study is its calculation of the social rate of returns in all the cases in our sample cities. Figure 5 describes the social rate of return in each city by population size. There is no obvious relationship between the social rate of return and population size, which implies that the social rate

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[21] This assumption is quite conservative because the average lifetime of the water-supply system in postwar Japan is considered as approximately 50 years (see Japan Water Works Association 1967a, p.505).

[22] We convert the costs in 1930 yen into costs in 2014 dollars using the CPI-U of the United States (16.7 in 1930) and the rate of exchange. The data on the rate of exchange in 1930 between Japanese yen and the US dollar (100 yen compared to 49.375 dollars) are taken from Financial Bureau of the Ministry of Finance (1931).

of return on modern water-supply systems did not depend on the scale of the city as well as their effect on mortality rates did not (see Section 4.2). [23] However, the same figure also reveals that there was considerable heterogeneity of the returns. Our result suggests that the likelihood of the project's success may depend highly on the situation the city faced. Both formal and informal institutions, such as the function of the local markets, the financial capability of local governments, and the social capital of the people, might affect supply- and demand-side behavior of citizens.

7 Conclusion

This study focused on the effect of the modern water-supply systems on the mortality rates in the cities of Japan during the 1920s and 1930s. Taking advantage of historical material documenting detailed information on the modern waterworks in each city, we examine the effect of the popularization of tap water on the mortality rates.

First, we found that not only the timing of installation but also the pace of the expansion project of water taps depended on large random components, such as natural disasters, economic fluctuations, and political issues. Second, we found that quality of tap water was high enough to prevent waterborne diseases using the criterion of bacteriological testing based on modern microbiology. Third, taking advantage of time variation within the same city owing to the popularization of tap water, we employ a city fixed-effects approach as our identification strategy. According to our baseline estimates, the modern water-supply systems account for approximately 27.1% of the decrease in the crude death rate between 1922 and 1940. A cost–benefit analysis shows that the social rate of return of the modern water-supply system was estimated to be 4,476%. Although the magnitudes of our baseline estimates were smaller than those of the clean-water technologies installed in the major cities of the United States between 1900 and 1936, the social rate of return in prewar Japan was slightly higher than that in major US cities. Finally, we found that the impact of water-supply systems did *not* depend on the scale of the city. This new finding suggests that the general finding in previous studies that waterworks improve mortality rates in major cities is robust.

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[23] Figure G.7 in the Appendix G shows the benefit of the modern water-supply systems and costs, and the social rate of return in cities ordered by installation year of the modern waterworks. Evidently, the social rate of return also did not depend on the installation year.

The results in this study support the evidence provided in previous studies, which stressed the importance of institutional interventions in the field of public health, and adds to the debate about the contribution of improvements in nutrition during the historical decline in mortality rates. In addition, our empirical evidence supports the recent results in development economics on the effects of the diffusion of piped water, quality of drinking water, and regulation policies.

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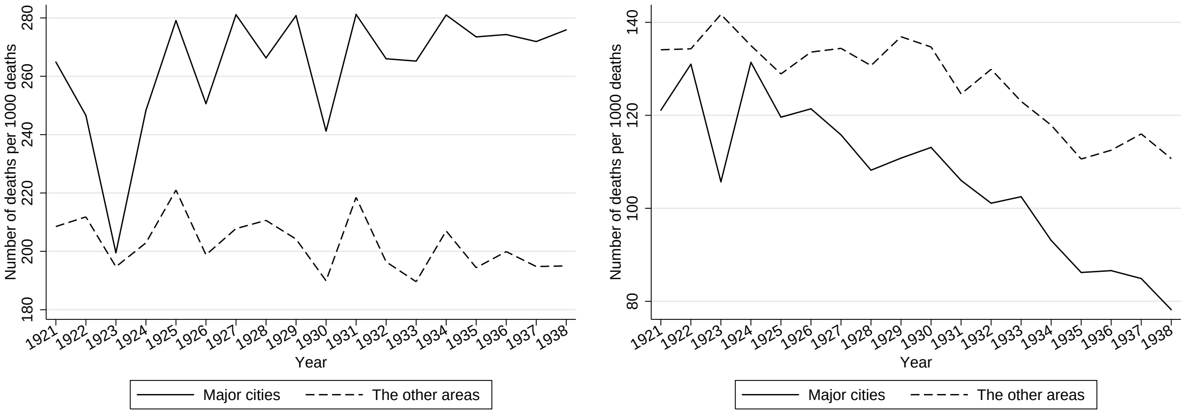
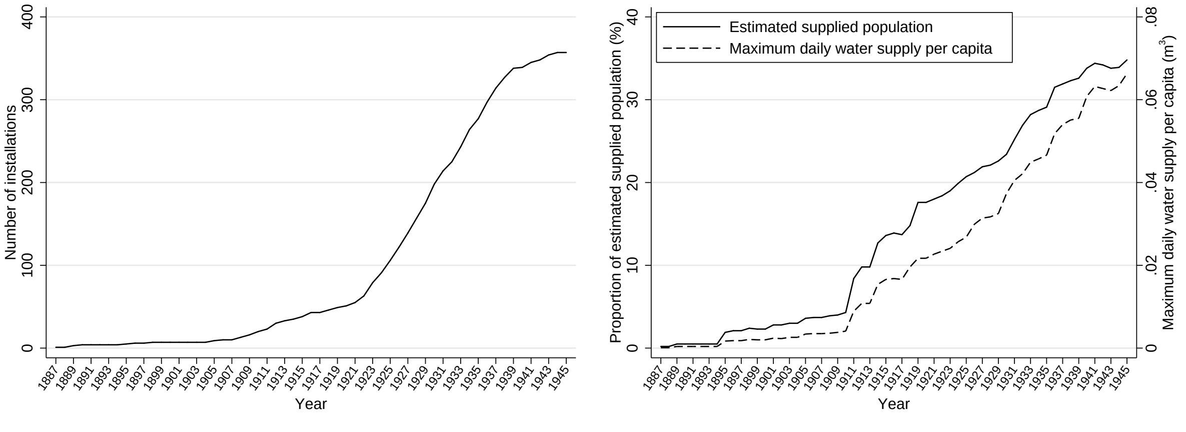


(a) Respiratory infectious diseases

(b) Gastrointestinal infectious diseases

Figure 1: Number of deaths attributed to infectious diseases per 1,000 deaths

Note: Major cities include those with a population lager than 100,000. The fall in the ratio in major cities at 1923 is caused by the Great Kanto Earthquake. The fall in the ratio of respiratory diseases in major cities in 1930 reflects the epidemic of diarrhea and enteritis among infants (see Figure G.4b in Appendix G). Source: Statistics Bureau of the Cabinet (1924b–1939b).



(a) Number of installations

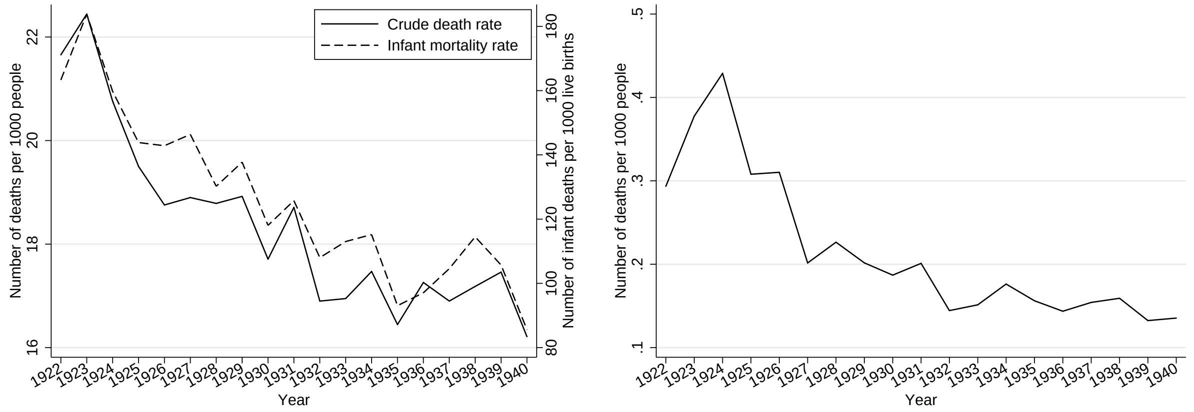
(b) Popularization and maximum daily water supply

Figure 2: Number of installations, proportion of estimated supplied population, and maximum daily water supply per capita.

Note: The number of installations means the number of modern water-supply systems established. The proportion of estimated supplied population is the planned supplied population divided by the overall population (%). Maximum daily water supply per capita is the available amount of maximum supplied water divided by the overall population (m^3). Source: Japan Water Works Association (1967a, pp.190, 200, 208).

Figure 3: Spatial distribution of sample cities

Note: Each circle represents the current location of the sample cities based on latitude and longitude information. *Source*: Data on latitude and longitude are from the database of the Geospatial Information Authority of Japan (see Appendix B).



(a) Crude death rate and infant mortality rate

(b) Typhoid death rate

Figure 4: Crude death rate, typhoid death rate, and infant mortality rate in the sample cities

Note: Crude death rate is the number of deaths per 1,000 people. Typhoid death rate is the number of deaths from typhoid fever per 1,000 people. Infant mortality rate is the number of infant deaths per 1,000 live births. *Source*: Data on population and number of crude deaths are from the Statistics Bureau of the Cabinet (1924a–1942a). Data on infant deaths are from the Statistics Bureau of the Cabinet (1925b–1939b, 1938a–1942a). The numbers of typhoid deaths are from the Sanitary Bureau of the Home Department (1924–1938), Sanitary Bureau of the Department of Welfare (1939–1940), and Population Bureau of the Department of Welfare (1942–1943).

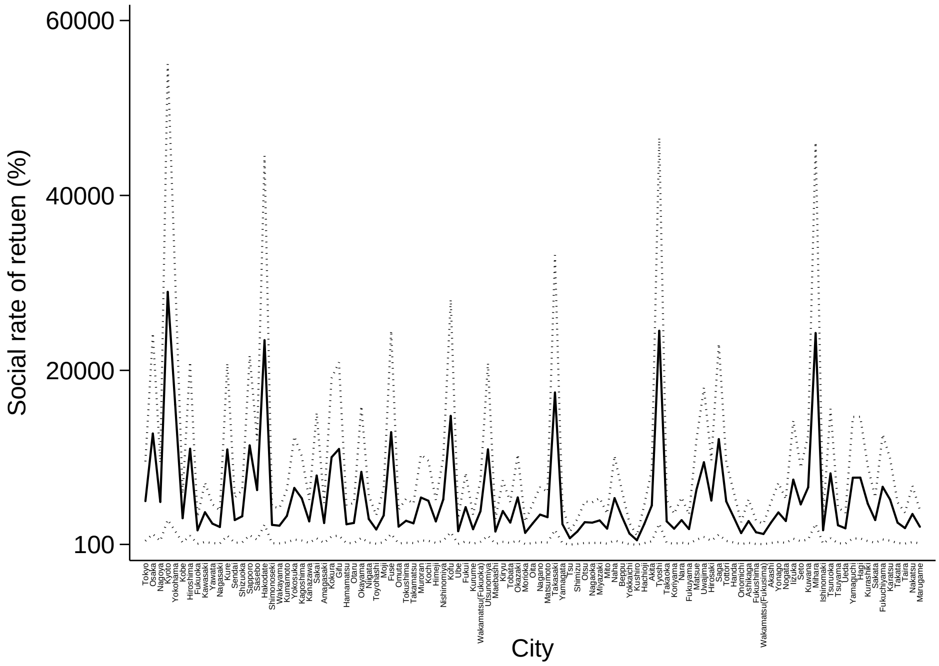


Figure 5: Social rate of return in the sample cities

Note: Both benefits and costs are the average annual benefits and costs of the modern water-supply systems in our sample cities. Social rate of return is the percentage ratio of the benefit versus cost. Aomori, Ichinomiya, and Matsuyama cities are not included owing to missing data on costs. Sample cities are arranged in order of the population size.

Table 1: Cause and uncertainties of modern water-supply projects; typical examples

List of cities	Start of the plan	Ground -breaking	Installation (Commencement)	Main factor of the installation	Uncertainties of the installation	Uncertainties of the expansion
Sapporo	1910	1934	1937	Decline in groundwater level	Water rights issue	Outbreak of WWII
Morioka	1929	1932	1935	Deterioration in quality of well water and spring water, drought, big fire	Acquisition of old and small water-supply system	Suspension of works for winter, decline in price, flood, outbreak of WWII
Sendai	1891	1913	1923	Groundwater shortage and poor groundwater quality due to geographical feature, big fire	Financial problems, flood, bad harvest, outbreak of Russo–Japanese War, WWI, and WWII	Water shortage during summer
Yamagata	1892	1918	1922	Collapse of ground layer due to heavy rain, flood, big fire	Increase in price, flood	Decline in amount of discharge at water source, dam break due to heavy rain
Fukushima	1913	1922	1925	Water shortage due to population growth and development of commerce and industry	Residents' opposition to preliminary design	Outbreak of WWII
Taira	1893	1917	1922	Poor well-water quality due to geographical feature, big fire	Outbreak of Sino–Japanese War, financial problems, revision to sluice gate area	Changes in attitude for water-source usage of coal mining company, confrontation between political parties
Ashikaga	1917	1929	1930	Poor well-water quality due to geographical feature	Rejection in the assembly, financial problems	Outbreak of Second Sino–Japanese War and WWII
Yokosuka	1912	1919	1922	Well-water shortage due to geographical feature, outbreak of Russo–Japanese War	Application of waterworks of naval station, outbreak of WWI	Great Kanto Earthquake, outbreak of Second Sino–Japanese War and WWII
Nagaoka	1901	1914	1927	Poor well-water quality due to geographical feature	Outbreak of Russo–Japanese War, Great Kanto Earthquake	Outbreak of Second Sino–Japanese War
Takata	1912	1924	1925	Poor well-water quality due to geographical feature	Outbreak of WWI	Deterioration of water-supply system, outbreak of WWII
Ueda	1914	1920	1923	Poor water quality due to geographical feature, drought in summer	Rising cost of materials	Flood, degradation of river bed
Yokkaichi	1919	1928	1932	Poor groundwater quality due to geographical feature, water supply for reclaimed land and ships	Acquisition and expansion of water-supply system for ships	Earthquake, outbreak of WWII
Himeji	1910	1927	1929	Poor well-water quality due to geographical feature	Rejection in city council, water right issues	Outbreak of WWII, consolidation of municipalities, demand for water for industrial use
Nishinomiya	1919	1922	1924	Poor well-water quality and well-water shortage due to geographical feature	Opposition by residents in water-source area, water right issues	Heavy rain, consolidation of municipalities, outbreak of WWII
Matsue	1895	1914	1919	Poor well-water quality due to geographical feature	Financial problems, outbreak of Russo–Japanese War and WWI, land acquisition, heavy snowfall	Drought, flood, outbreak of WWII, rupture of lead pipe due to cold air mass
Tokushima	1907	1924	1926	Poor well-water quality due to geographical feature	Rejection in city council, outbreak of WWI, residents' opposition	Water-source shortage, outbreak of WWII
Takamatsu	1890	1914	1921	Poor water quality and water shortage due to geographical feature	Difficulties of finding water source, outbreak of WWI	Decline in pumping discharge, development of subwater source, outbreak of WWII
Fukuoka	1889	1916	1922	Poor well-water quality due to geographical feature, big fire	Opposition by residents, outbreak of Russo–Japanese War and WWII, resignation of city mayor	Outbreak of WWII
Nakatsu	1920	1926	1928	Poor water quality of old water-supply system, fire prevention	Great Kanto Earthquake, consolidation of municipalities	Consolidation of municipalities, infiltration of seawater to water source
Kagoshima	1913	1916	1919	Poor water quality of old water-supply system, frequent occurrence of fire	Outbreak of WWI, financial problems, tunnel construction, difficulty obtaining materials	Consolidation of municipalities, water shortage in summer

Note: The cities listed above are the municipalities in our sample that have representative reasons for installation and typical uncertainties in the process of expansion projects. The cities listed above include towns that installed modern water-supply systems after 1919 and were reorganized as cities before 1940. *Sources*: Japan Water Works Association (1967b, 1967c, 1967d).

Table 2: Number of bacterial colonies (/ml) in source water and taps

Year	Number of observations	Bacterial colonies (/ml) (a)Source water	(b)Taps	(a)-(b)
1922–1925	129	755.7	20.0	735.7 ‡
1926–1928	139	535.6	22.4	513.1 ‡
1929–1931	171	521.3	16.1	505.3 ‡
1932–1934	202	401.8	15.5	386.2 ‡
1935–1937	207	388.0	9.3	378.7 ‡
1938–1940	207	348.3	7.3	341.0 ‡
Overall	1055	468.9	14.2	454.6 ‡

Note: Cities that recorded the number of bacterial colonies at both sampling points are used from our sample, described in Section 3. The paired t-test is used to test whether the mean of the number of bacterial colonies is the same in two water-sampling points. ‡ represents statistical significance at the 1% level. *Source*: Numbers of bacterial colonies are obtained from the Federation of Water Authorities (1922–1932) and Water Works Association (1934–1943); the timing of installation of filtration technologies is obtained from the Japan Water Works Association (1967b, 1967c, 1967d).

Table 3: Summary statistics of mortality rate and variables of interest

	Observations	Mean	Std.Dev.	Min	Max
Panel (a): Dependent variables for main analysis					
Crude death rate	1649	18.28	3.12	10.94	40.94
Typhoid death rate	1427	0.19	0.17	0.01	1.43
Infant mortality rate	662	116.72	30.71	33.47	244.20
Panel (b): Dependent variables for cause-specific analysis					
Gastrointestinal infection death rate	264	2.07	0.67	0.47	4.12
Typhoid death rate	264	0.27	0.25	0.03	2.23
Dysentery and diarrhea death rate	264	1.79	0.61	0.37	3.91
Respiratory infection death rate	264	4.60	0.90	2.88	7.66
Measles	264	0.23	0.25	0.00	1.70
Scarlet fever	257	0.01	0.02	0.00	0.36
Whooping cough	264	0.16	0.10	0.02	0.92
Diphtheria	264	0.07	0.05	0.00	0.24
Influenza	264	0.09	0.06	0.00	0.36
Tuberculosis	264	1.95	0.39	1.16	3.34
Bronchitis	264	0.34	0.14	0.13	1.18
Pneumonia	264	1.76	0.50	0.16	4.03
Panel (c): Variables of interest					
Water	1649	5.75	4.25	0.00	18.05
Filtered water	1468	5.83	4.26	0.00	18.05

Notes: *Crude death rate* is the number of total deaths per 1,000 people (parts per 1,000, permil). *Typhoid death rate* is the number of deaths due to typhoid per 1,000 people (permil). *Infant mortality rate* is the number of infant deaths per 1,000 live births (permil). All cause-specific death rates are defined as the proportion per 1,000 people (permil). *Gastrointestinal infection death rate* includes deaths from typhoid, dysentery, and diarrhea. *Respiratory infection death rate* includes deaths from measles, scarlet fever, whooping cough, diphtheria, influenza, tuberculosis, bronchitis, and pneumonia. *Water* is the number of water taps, including both metered and communal taps, for households and business divided by 100 total population (percentage points). *Filtered water* is the number of taps with filtered water, including both metered and communal taps, for households and business divided by 100 total population (percentage points). Details of the data sources of each variable used in the regression are provided in the text and the Appendix B.

Table 4: Baseline estimates: impact of modern water-supply system

	Crude death rate				Typhoid death rate				Infant mortality rate			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Water	-0.165**	-0.165**	-0.166**	-0.166**	-0.008*	-0.008*	-0.008*	-0.009*	-1.072**	-0.949*	-1.268***	-1.216**
	(0.072)	(0.074)	(0.071)	(0.075)	(0.005)	(0.005)	(0.005)	(0.005)	(0.449)	(0.483)	(0.446)	(0.495)
Baseline controls												
Demographic controls	Yes	Yes			Yes	Yes			Yes	Yes		
Socioeconomic controls	No	Yes			No	Yes			No	Yes		
Demographic controls ×period dummy			Yes	Yes			Yes	Yes			Yes	Yes
Socioeconomic controls ×period dummy			No	Yes			No	Yes			No	Yes
F-statistic p-value on joint significance of baseline controls	0.0000	0.0000	0.0000	0.0000	0.2025	0.0015	0.1940	0.0017	0.5968	0.4230	0.3459	0.0238
City- and Year- fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.8211	0.8237	0.8229	0.8262	0.5166	0.5217	0.5182	0.5282	0.8988	0.8960	0.8994	0.8971
Number of clusters	108	108	108	108	108	108	108	108	104	104	104	104
Number of observations	1649	1639	1649	1639	1429	1416	1429	1416	662	656	662	656

Notes: Observations are at the city-year level. Dependent variables are any one of the crude death rate, typhoid death rate, and infant mortality rate. Crude death rate is the number of deaths per 1,000 people. Typhoid death rate is the number of deaths from typhoid fever per 1,000 people. Infant mortality rate is the number of infant deaths per 1,000 live births. *Water* is the number of water taps per 100 total population. Demographic controls include the natural logarithm of the total population and shares of population aged 0–14, 15–24, and 25–59 years. Socioeconomic controls include the natural logarithm of total revenue, number of doctors per 100 population, and proportion of factory workers per 100 population. Period dummy is an indicator variable that equals one for the periods after 1931. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table 5: Flexible estimates: impact of modern water-supply system

	Crude death rate			Typhoid death rate			Infant mortality rate		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Water	1.216	1.371	-4.492	0.030	0.029	0.115	2.157	1.577	-60.541
	(1.256)	(1.196)	(5.537)	(0.049)	(0.047)	(0.417)	(7.419)	(7.343)	(62.684)
$Water \times Population$	-0.122	-0.135	0.803	-0.003	-0.003	-0.018	-0.246	-0.221	9.422
	(0.114)	(0.109)	(0.903)	(0.004)	(0.004)	(0.067)	(0.589)	(0.583)	(9.407)
$Water \times Population^2$			-0.039			0.001			-0.372
			(0.037)			(0.003)			(0.350)
Baseline controls	Yes			Yes			Yes		
Baseline controls ×period dummy		Yes	Yes		Yes	Yes		Yes	Yes
F-statistic p-value on joint significance of baseline controls	0.0007	0.0000	0.0000	0.0028	0.0020	0.0017	0.5160	0.0742	0.0003
City- and year- fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.8259	0.8290	0.8350	0.5222	0.5287	0.5292	0.8961	0.8972	0.8976
Number of clusters	108	108	108	108	108	108	104	104	104
Number of observations	1639	1639	1639	1416	1416	1416	656	656	656

Notes: Baseline controls include both demographic and socioeconomic variables. Baseline controls in columns (3), (6), and (9) also include *Population* squared. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table 6: Robustness to controlling for additional demographic and meteorological factors

	Crude death rate		Typhoid death rate		Infant mortality rate	
	(1)	(2)	(3)	(4)	(5)	(6)
Water	-0.164**	-0.174**	-0.009*	-0.010**	-1.072**	-1.262**
	(0.073)	(0.076)	(0.005)	(0.004)	(0.498)	(0.528)
Baseline controls	Yes		Yes		Yes	
Baseline controls ×period dummy		Yes		Yes		Yes
Additional controls	Yes		Yes		Yes	
Additional controls ×period dummy		Yes		Yes		Yes
F-statistic p-value on joint significance of baseline controls	0.0000	0.0000	0.0011	0.0013	0.3277	0.0121
F-statistic p-value on joint significance of additional controls	0.0038	0.0035	0.8082	0.0082	0.3814	0.0174
City- and Year- fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects × Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.8285	0.8318	0.5250	0.5412	0.8979	0.9008
Number of clusters	108	108	108	108	102	102
Number of observations	1638	1638	1416	1416	656	656

Notes: Baseline controls include both demographic and socioeconomic variables. Additional controls include the sex ratios of the population aged 0–14, 15–24, 25–59, and 60+ years, monthly average of the annual temperature (Celsius), total amount of annual precipitation (millimeters), monthly average humidity (percentage points), and monthly average actual sunshine duration (hours). ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table 7: Robustness to use of alternative definitions of the coverage of tap water

	Crude death rate		Typhoid death rate		Infant mortality rate	
	(1)	(2)	(3)	(4)	(5)	(6)
Filtered water	-0.196**	-0.207**	-0.010**	-0.011**	-1.152**	-1.277**
	(0.078)	(0.081)	(0.005)	(0.005)	(0.514)	(0.540)
Baseline controls	Yes		Yes		Yes	
Baseline controls ×period dummy		Yes		Yes		Yes
Additional controls	Yes		Yes		Yes	
Additional controls ×period dummy		Yes		Yes		Yes
F-statistic p-value on joint significance of baseline controls	0.0000	0.0000	0.0020	0.0008	0.5549	0.1498
F-statistic p-value on joint significance of additional controls	0.0059	0.0018	0.9222	0.0133	0.0414	0.0000
City- and Year- fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects × Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.6938	0.7010	0.3786	0.4001	0.8520	0.8561
Number of clusters	95	95	95	95	91	91
Number of observations	1458	1458	1266	1266	592	592

Notes: *Filtered water* is the number of taps with filtered water, including both metered and communal taps, for households and business divided by 100 total population (percentage points). Baseline controls include both demographic and socioeconomic variables. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table 8: Placebo test: impact of lead values of the coverage of tap water

	Crude death rate			Typhoid death rate			Infant mortality rate		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$Water_{t+3}$	-0.063			-0.003			-0.342		
	(0.043)			(0.005)			(1.248)		
$Water_{t+2}$	-0.008	-0.031		-0.005	-0.007		-0.424	-0.967	
	(0.056)	(0.052)		(0.006)	(0.005)		(1.041)	(0.920)	
$Water_{t+1}$	0.046	0.028	-0.003	0.001	0.001	-0.0003	0.259	-0.160	0.086
	(0.050)	(0.050)	(0.058)	(0.004)	(0.004)	(0.004)	(0.846)	(0.816)	(0.628)
$Water_t$	-0.245*	-0.205*	-0.173	-0.010*	-0.010**	-0.009*	-1.381**	-0.657	-1.209**
	(0.124)	(0.114)	(0.106)	(0.005)	(0.005)	(0.005)	(0.580)	(0.587)	(0.579)
Baseline and additional controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City- and Year- fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.8500	0.8423	0.8356	0.5966	0.5864	0.5528	0.9344	0.9345	0.9060
Number of clusters	102	107	107	101	104	106	80	90	92
Number of observations	1160	1308	1467	921	1068	1231	263	374	496

Notes: Baseline controls include both demographic and socioeconomic variables. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table 9: Estimation results for cause-specific death rates

Dependent variable	*Water*	*R*-squared	Number of clusters	Number of observations	Baseline controls × period dummy	City- and Year-fixed effects	City fixed effects × Year
Gastrointestinal infections	-0.079*** (0.028)	0.8319	26	264	Yes	Yes	Yes
Typhoid fever	-0.043*** (0.012)	0.6194	26	264	Yes	Yes	Yes
Dysentery and diarrhea	-0.036* (0.019)	0.8684	26	264	Yes	Yes	Yes
Respiratory infections	-0.040 (0.046)	0.7347	26	264	Yes	Yes	Yes
Measles	0.001 (0.009)	0.4786	26	264	Yes	Yes	Yes
Scarlet fever	-0.003*** (0.001)	0.3139	24	257	Yes	Yes	Yes
Whooping cough	0.002 (0.005)	0.4279	26	264	Yes	Yes	Yes
Diphtheria	-0.003 (0.002)	0.8101	26	264	Yes	Yes	Yes
Influenza	0.000 (0.003)	0.6602	26	264	Yes	Yes	Yes
Tuberculosis	-0.002 (0.013)	0.9005	26	264	Yes	Yes	Yes
Bronchitis	-0.002 (0.005)	0.8576	26	264	Yes	Yes	Yes
Pneumonia	-0.033 (0.027)	0.7558	26	264	Yes	Yes	Yes

Notes: All cause-specific death rates are defined as the proportion per 1,000 people. Of the sample for scarlet fever, Kawasaki and Moji cities are dropped because of missing values. Gastrointestinal infections include deaths from typhoid fever, dysentery, and diarrhea. Respiratory infections include deaths from measles, scarlet fever, whooping cough, diphtheria, influenza, tuberculosis, bronchitis, and pneumonia. Baseline controls include both demographic and socioeconomic variables. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table 10: Social rate of return of modern water-supply systems

	Estimates	95% lower CI	95% upper CI
Crude death-rate reduction due to modern waterworks	-0.1664	-0.0168	-0.3160
Average number of people saved each year	23,967	2,418	45516
Average life expectancy	40.2		
Average person-years saved each year (thousand)	963	97	1,828
Value of person-year in dollars	4,753		
Average benefits each year in millions of dollars	4,546	462	8,690
Average costs each year in millions of dollars	102		
Social rate of return (%)	4,476	451	8,501
Cost per person-year saved in dollars	106	1,053	56

Notes: Crude death-rate reduction due to modern waterworks is the estimated coefficient on the coverage of tap water in our baseline estimate reported in column (4) of Table 4. Both benefits and costs are calculated in 2014 dollars. The procedure for calculating benefits in detail is described in Appendix F.

Appendices

Appendix A Institution of the modern water-supply system

A.1 Waterworks Ordinance

The Japanese government established the basic policy on waterworks project management by cabinet meeting in June 1887. In 1888, the Sanitary Bureau of the Home Department established the following policy principles: "Water supply projects should naturally be public undertakings at the city, town, and village levels, and to make this point clear, without protective supervision of such projects, it will not be possible to achieve objectives concerning public health. Furthermore, the administration of water-supply projects should be, in principle, a public service provided by cities, towns, and villages. If a municipality is unable to do so for financial reasons, the organization of a private company shall be permitted." Based on this, in October 1888, the Sanitation Bureau drafted and submitted to the Bureau of Legislation a proposal for a Waterworks Ordinance (the old Water Works Law). However, the final draft permitted only the public management of waterworks by cities, towns, and villages. The proposed Waterworks Ordinance passed by the cabinet in December 1889 was submitted to the senate in January 1890, and was passed into law as Act No. 9 of February 12, 1890. [24]

The reason water-supply projects were classed as "public undertakings at the city, town, and village levels" (see previous paragraph) was due to the new legal organization of cities, towns, and villages (*Shichoson-sei*) in April 1888, by which the local autonomy of these municipalities was legally recognized. Under the new system, a municipality became an independent juridical person charged with public works and other delegated responsibilities and capable of establishing ordinances and regulations. [25] In addition,

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[24] For a more detailed account regarding the Waterworks Ordinance, see the Japan Water Works Association (1967a, pp.351–363). Due to the urgent nature of the ordinance, it was promulgated prior to the inaugural session of the Imperial Diet (November 29, 1890), and as such, was established only with the approval of the Emperor. For this reason, it is classified as an "ordinance," although it was issued much in the same way as any other law (see Japan Water Works Association 1967a, pp.363–363).

[25] City, town, and village assemblies were comprised of publicly elected honorary members voted for under the class-electoral system. Councils made decisions on all issues at the municipal level and those for which they were responsible. Executive power was invested in city mayors and councils (comprised of the mayor, deputy mayor, and honorary council members) in the case of cities, and town and village heads in their respective municipalities. City mayors were selected by the Minister for Home Affairs from among individuals recommended by city assemblies, while others were appointed via elections at the city, town, and village level.

in 1890, the prefectural and county systems (*Fuken-sei, Gun-sei*) were put in place, by which prefectures and counties were given regional government status.

Nevertheless, the Waterworks Ordinance was amended in March 1911 due to increasing demand for water-supply systems. This amendment allowed for corporate entities other than the municipality to operate water-supply systems under the following three conditions. (1) Installation of a water-supply system within the municipality would be required for the purposes of land development; (2) the relevant municipality did not have access to the requisite funds and, (3) operations were to be carried out with the aim of capital amortization. Despite this, the government authorized private management of waterworks only in exceptional circumstances, based on the principle of municipal management (see Japan Water Works Association 1967a, pp.363–365).

As a result, there were no applications from entities seeking this exemption after the ordinance was revised, such that two further revisions relaxing these conditions were carried out in April 1913. Conditions (1) and (3) were removed so that entities other than the municipality could manage water-supply systems if the city, town, or village was unable to provide funds. In addition, regulations concerning the purchase of waterworks prior to and after the period of management licensing were relaxed (see Japan Water Works Association 1967a, pp.365–368). These two revisions included prefectures in the definition of corporate entities, so that by the 1920s, waterworks managed by prefectural governments came into existence. Examples include small-scale systems in Yamaguchi and Okayama prefectures, and larger systems in Kanagawa, Chiba, and Osaka prefectures. Thus, during the inter-war periods, waterworks constructed and operated by private firms and prefectural administrations, although few, did exist. Notwithstanding, the present study focuses solely on modern water-supply systems managed by cities. However, those exceptional systems operated by entities other than cities should also be studied for their public health-related effects.

The Waterworks Ordinance underwent a third revision in April 1921. Up until then, the installation of waterworks was carried out with the authorization of the Home Minister; however, some small-scale, simple water-supply systems were installed without this formality. As a result, part of the Home Minister's authority was delegated to the prefectural governor and the relevant procedures were simplified. Specifically, the Home Minister could now delegate the authorization for new installations of waterworks servicing populations of less than 10,000 people and for the reconstruction or extension of existing waterworks with planned construction costs of less than 30,000 yen (see Japan Water Works Association 1967a, pp.368–369). Home Department Ministerial Ordinance No. 22 of July 1921 determined that prefectural governors were able to authorize small-scale waterworks to supply less than 10,000 people on the basis of a relatively simple prospectus, which omitted prescribed blueprints and other attachments. Ministerial Ordinance No. 29 of August 1928 modified part of the abovementioned Ministerial Ordinance No. 22, specifying the items to be described in documents attached to the prospectus (see Japan Water Works Association 1967a, pp.370–371). These comprised the chief revisions made to the Waterworks Ordinance in the prewar period.

A.2 Regulations and charges of water usage

Local governments operating water-supply systems established their own ordinances and rules. Depending on the municipality, these were known variously as waterworks-usage rules, waterworks-usage regulations, waterworks-supply rules, and water-supply regulations.

For example, the city of Yokohama, the first to introduce a modern water-supply system in Japan, established the first waterworks-supply rules in the country in 1887. These rules established the following: (1) Different water-service fees would be paid by Japanese citizens versus foreigners, wherein foreigners would pay five times the rate payable by citizens; (2) the gallon was established as the unit for water supplied, as foreign water meters were used, and (3) water for cattle and horses, drawn from special taps, was subject to a separate fee. Similarly, in Osaka, a range of regulations was established, including the Osaka municipal provisional regulations for waterworks supply, waterworks rules, and waterworks-usage regulations, while Tokyo established its own waterworks-supply rules and waterworks-usage regulations. These established provisions for water-service fees, fee collection, and penalties for breaking the rules.

As discussed in Subsection 2.2.2, unmetered taps were most common in the early stages of modern water-supply systems. These taps had several advantages. For instance, estimation was simple, they did not require a meter, and it was easier to predict receipts and payments. Despite this, as users of these taps increased along with the quantity of water consumed, measures were taken to ensure that all taps were metered from the

1920s (see Japan Water Works Association 1967a, p.464). For example, the following cities revised their water regulations setting a goal for the complete transition to metered water taps: Nagoya (1920), Tokyo (1921), Sakai City (1925), Yokohama (1926), Utsunomiya (1929), and Nagasaki (1932). Metered taps allowed for fairer and more logical collection of service fees, helped to reduce wasteful spending, and provided important information on water supply to help inform plans for new installations. During the Second World War, measures were taken in various cities to increase water-service fees, simplify administrative procedures, and reduce the frequency of bill collection (see Japan Water Works Association 1967a, pp.454-461). As this discussion clarifies, pre-Second World War water-supply systems were organized by each municipality and no two systems were the same. However, the transition from unmetered to metered taps was made in each city, and water-supply systems took on much the same characteristics that they have today.

Meanwhile, those at the receiving end of supply systems gradually became more acquainted with their usage. In cities that introduced modern water-supply systems relatively early on, many residents were unaware of the procedures involved in installing the new systems. For this reason, measures were taken to encourage the uptake of water supply in homes, such as the distribution of leaflets and posters explaining how to apply for a new installation, and employees from the bureaus of waterworks visited households to solicit applications (see Japan Water Works Association 1967a, p.468). Waterworks projects were operated by city, town, and village administrations and thus, the installation of water pipes was carried out directly by these municipalities. For instance, the Tokyo municipal waterworks-usage regulations determined that the city would be responsible for laying new water pipes in order to avoid any irregularities related to fee collection and to prevent leakages due to the use of substandard material (see Bureau of Waterworks Tokyo Metropolitan Government 1999b, p.211). [26] As a result, households could not easily change their water bills illegally. The apparatus for water supply was to be installed by the owner or landlord of a residence, and new installations on behalf of tenants were not accepted. [27]

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[26] However, in some instances, installation using one's own material and labor was permitted in the case of metered water services beyond a defined location downstream from the meter (see Japan Water Works Association 1967a, pp.470–472).

[27] There were exceptions to this in some cities. For example, during the 1930s in Tokyo and Okazaki cities, new installations went ahead upon request from the tenant of a rented residence, which was considered as obtaining the property owner's authorization. Also in Takasaki and Yamagata cities, tenants were able to accept new installation requests (see Japan Water Works Association 1967a, pp.474).

In addition, fee systems varied according to the municipality, such that it is difficult to make any general comments about them. Nevertheless, during the 1920s and 1930s, which are the focus of the present study, "usage differentiated fee systems" were commonly established, water quantities were measured in cubic meters, and fee payments were made via collection, where previously it had been submitted by the customer (see Japan Water Works Association 1967a, p.480). Four general water-usage categories were defined: household, bathhouse, communal, and other. In the mid-1930s, the basic rate for households was approximately 1 yen per 10 cubic meters, and around 7 sen (0.07 yen) per cubic meter for excess water (Water Works Association 1935, pp.1–7). In Tokyo in 1950, the average monthly amount of water used per household metered tap was 8.6 cubic meters (Iwasaki 1957, p.7), and so, a monthly household water bill may be estimated at 0.86 yen per month. As this figure is for post-war water fees, we can assume that a prewar monthly water bill came to less than 1 yen.

According to Nakagawa (1985), a factory worker in a Japanese city had in 1932 accrued expenditure of around 78 yen, 3.9 yen (5%) of which was spent on heating and lighting (p.393). Considering these amounts, the water fee described above was a realistic amount that accounted for a comparatively small portion of the worker's living expenses. Members of the new urban middle classes in the same year had accrued expenditure of around 88 yen, and spent the same 5% on heating and lighting (p.395), and so, water-usage fees can be considered cheap for this class also. However, between 1931 and 1934, members of the urban underclass spent around 39 yen, with estimated household expenses, including heating and lighting costs, of around 6.24 yen (or 16% of all expenditure) (p.398). For these people, a water bill of just under 1 yen may have been a relatively large expense. In any event, a 1934 survey of welfare recipient households in Tokyo found that 76 of the 203 households surveyed, or 37.4%, relied on water wells, observing that "many households continue to utilize wells" (Tokyo City Office 1935, p.21).

A.3 Financial affairs

Each city's water-supply projects were managed under a variety of financial arrangements. For example, construction costs were sometimes managed under special accounts, or might be switched midway from general accounts to special accounts. Surplus earnings were often kept as reserves to be used to improve service in the future, without being fed back into general accounts. Revenues by order of size were fee revenues, service installation revenues, and miscellaneous revenues. Revenues from municipal bonds and surpluses carried forward from general accounts provided another temporary source of funds, which were commonly used as funds to improve infrastructure. Service maintenance and repair costs, interest payments on public loans, and capital repayments accounted for the main annual expenditure (Japan Water Works Association 1967a, p.531).

The most important source of funds for the new installation or expansion of a water-supply system came from the issuing of bonds. [28] A part of source of funds was applied funds from national or prefectural subsidies and balance carried forward from general accounts. [29] For example, Osaka sourced its entire waterworks construction cost of 2.5 million yen from waterworks bonds, a little more than one-third of which was repaid from the national subsidy, and the remainder from water-service fees and municipal taxes. Similarly, Tokyo covered its entire initial waterworks investment of 9.18 million yen from public bonds (see Japan Water Works Association 1967a, pp.531–532). However, during the early days of the modern supply systems, applications for new water services were fewer than expected, so that fee revenues did match previous estimates and the finances of waterworks projects were less than healthy. Of the hundreds of thousands of households in Osaka, there were less than 3,500 early applications to receive the new water service. A sudden jump in prices in Nagoya meant that water-service equipment became costly and, as potential customers shied away, fee revenues there were significantly lower than initial forecasts (see Japan Water Works Association 1967a, pp.532–533). Resulting shortfalls were covered from general accounts, that is, municipal taxes. Meanwhile, repair and maintenance costs and principal and interest repayments on debt accounted for the large majority of each city's expenditure. For example, Yokohama's power costs at the time of founding were comprised of coal (20%) and personnel costs (42%), while in Osaka in 1906, 36% of its expenditure went to repaying the principal and interest on loans (Japan Water Works Association 1967a, p.534).

As taps become metered, each city became able to reduce wasteful water use and im-

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[28] As of 1921, bonds for public health and waterworks projects accounted for 17.4% of outstanding debt at the end of the financial year. In 1930, this figure was 13%. Bonds for water projects accounted for 9.5% of outstanding debt in 1935 and 10.3% in 1940. The percentage of bonds for waterworks projects dropped as Japan entered the Second World War; however, they accounted for around 10% of public debt throughout the 1920s and 1930s (see Japan Water Works Association 1967a, p.572). For information on local government bonds, see the Japan Water Works Association (1967a, pp.559–587).

[29] For more information on national subsidies, see Subsection 2.2.3.

prove the efficiency of delivery, while also stabilizing the operation of waterworks as fee revenues improved. Financial support had been sourced previously from municipalities' budgets in order to repay debt; however, during this period, revenues from waterworks were fed back into budgets. Nevertheless, numerous financial shocks affected the management of each city's waterworks and the rate of uptake of the new supply systems. These included the First World War, Great Kanto Earthquake, Showa Depression, and Second World War (see Japan Water Works Association 1967a, pp.536–539). As shown in Figure G.4, the rates of uptake of water-supply systems for each city by no means increased consistently. If anything, uptake was significantly affected by unexpected economic and political events or sudden natural disasters.

Finally, we explain the methods used to procure funds to construct waterworks. As mentioned in this section, the primary source of funds used by municipalities to establish waterworks was the issuance of bonds. Financing of water-supply projects using government funds was arranged via these local government bonds. Government funds were managed by the Treasury's Deposits Section, and lending of regional funds only began in earnest with the passing of the Law on Deposits, Deposits Section in 1925 (Japan Water Works Association 1967a, p.575). Lending by the Deposits Section for waterworks projects was conducted indirectly until the mid-1920s (called *Kansetsu yuzu hoshiki*). That is, the Deposits Section would take on industrial bonds issued by Nippon Kangyo Bank (NKB), supplying funds at lower interest than the market rate, while the NKB would provide loans to local governments through its network of branches. However, this indirect lending arrangement incurred a commission on the part of the bank, to be paid by the local government. For this reason, direct lending increased after the Law on Deposits came into operation (called *Chokusetsu yuzu hosiki*). In 1921, of the balance of funds under management by the Deposits Section, industrial bonds accounted for 12.4 million yen, while municipal bonds accounted for 84 million yen. In 1940, they comprised 228 million yen and 1.119 billion yen, respectively (see Japan Water Works Association 1967a, p.577).

Of the Deposits Section's balance of regional bonds, those issued for water-supply projects accounted for 14.5% in 1921, 10.6% in 1930 and 10.3% in 1940, remaining stable at around 10%. Conversely, bonds for waterworks projects accounted for 3% of total funds managed by the Deposits Section in 1926 and 3.2% in 1930, remaining around this level until the wartime system was instated, whereupon this figure dropped sharply to as low as 1.3% in 1940. *The History of Water Supply System in Japan* concludes that while "the lending of waterworks projects by the Deposits Section was relatively stable among the municipal bonds in prewar periods," it nevertheless "could not avoid the instabilities brought about by society-wide trends" (Japan Water Works Association 1967a, p.577). This confirms the contention of the present study, that is, that the spread of modern waterworks systems was determined largely by the occurrence of sudden shocks.

A.4 Government subsidies

We refer to the effect of the approval of government subsidies on the timing of installation and on the expansion of the number of water taps of modern water-supply systems. The government established a national subsidy for the construction of water-supply systems in 1888, which covered around one-third of project costs in three urban prefectures and five ports. As a result, Tokyo, Osaka, Kyoto, Yokohama, Kobe, Nagasaki, Hakodate, and Niigata, which were all comparatively large and heavily populated cities, had introduced modern water-supply systems by the end of the 20th century. A subsidy scheme was established in 1900 for other cities, encouraging the installation of systems in medium-sized cities also. Around 1920, subsidization was extended further to towns and villages, with many installations subsequently occurring in small municipalities. Cities, towns, and villages were eligible to receive subsidies on the basis of national subsidy selection criteria set on October 14, 1921. These criteria prioritized new installations over the extension of existing facilities, and those cities, towns, or villages in financial difficulty were given precedence if multiple projects had similar merits. In addition, the criteria established precedence of city installations over those for towns and villages (see Japan Water Works Association 1967a, p.197). Thus, national subsidies initially were directed at heavily populated, larger cities as a matter of precedence, while medium- and small-scale municipalities benefited from subsidization largely after the 1920s.

However, the national subsidy was not paid out in one lump sum prior to the construction of waterworks, but instead a percentage of the total amount was granted each year. Accordingly, "in the first year of waterworks construction, the national subsidy provided only a very small amount of money that was of almost no assistance." Furthermore, "as the subsidy was dispensed over a long-term period, its effects in terms of financing waterworks construction were very much diluted, and in reality, was merely allocated to the repayment of national bonds" (Japan Water Works Association 1967a, pp.549–550). For instance, the Tokyo waterworks, commenced in 1894 and with a total construction cost of 6.5 million yen, each year received 150,000 yen in government assistance over 15 years. This amount was used to repay the principal and meet interest payments on public bonds issued for waterworks projects (Japan Water Works Association 1967a, p.550). For this reason, while subsidization by the national government did encourage the introduction of modern water-supply systems, it did not greatly affect the rate of tap installations after the construction of these systems.

A.5 Water purification technologies

The filtration facilities are the most important piece of technology in the purification process. This technology involved passing water through layers of sand, thereby removing impurities and bacteria, including pathogens, by the action of a membrane of microorganisms that forms on the surface of the sand layers. The filtration technology can be divided broadly into two types: slow and rapid sand filtration. A slow speed filter was able to purify around 3 meters of water in 1 day, while a rapid filter could handle around 120 meters of water a day. [30] In general, slow-speed filtration technology was used when the turbidity of the original state of water was relatively low, while faster filters were used in places where water demand was higher and water quality lower, commonly in combination with flocculants to settle contaminants. [31] Cities that introduced modern water-supply systems sourced their water from surface flows with comparatively good water quality and hence, tended to use the slower filtration technologies. [32] As discussed below, cities that enjoyed particularly pure water did not install filtration ponds but rather supplied raw water directly from settling ponds. From the 1920s, filtration plants using rapid filtration

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[30] The photograph of slow sand-filtration system (*rokachi*), rapid–filtration machine *rokaki*), and pump room (*shokuto*) in water–purification plants are shown in Figure H.5–H.7 in Appendix H.

[31] Cities that installed slow filtration basins also constructed settling basins, in which raw water would accumulate and any particles allowed to precipitate. Using this process, water was stored in settling basins for around 24 hours.The speed of this process was established in accordance with Hazen's equation (Japan Water Works Association 1967a, p.599).

[32] The percentage of water-supply systems reliant on surface flows was 90% in 1921, 80% in 1930, and 79% in 1939. As discussed in the previous subsection, the construction of waterworks often became entangled in political problems concerning the acquisition of water rights, and for this reason, an increasing number of systems utilized underground water during the interwar period (see Figure G.5 in the Appendix).

technology were constructed gradually in the larger cities, such as Osaka, Yokohama, and Nagoya. In places where raw water was turbid, flocculants, such as aluminum sulfate, were added to settling ponds. However, according to the Japan Society of Civil Engineers (1965), the vast majority of cities still utilized slow-speed filtration technologies; 90% of cities in 1912, 91.9% in 1921, 78.6% in 1930, and 71.2% in 1939. Conversely, those with rapid filtration accounted for only 10%, 10.8%, 19%, and 23.7% of Japanese cities in these respective years. [33] Thus, slow-speed filtration technology formed the cornerstone of water purification throughout 1920s and 1930s of Japan. [34]

Second, in the present day, the main purification technique is chlorine disinfection using rapid filtration. However, chlorination was by no means then a standard purification technique because slow filtration technologies were by far the most common in prewar Japan as mentioned above. Cities that did chlorinate water did so only intermittently, such as during the summer months, during an outbreak of an infectious disease, or when cleaning service reservoirs. Moreover, chlorine was used in purification plants in very low concentrations of around 0.1–0.3 parts per million (ppm), with much care taken to ensure water coming from city taps contained no traces of chlorine odor (see Japan Water Works Association 1967a, pp.618–621). [35] Chlorination was constant in some of the largest cities using rapid filtration, yet again, only very low concentrations of below 0.3 ppm were used. Although chlorination became more widespread at the outbreak of the Second World War, concentrations remained low at around 0.1–0.3 ppm. After Japan's defeat in the Second World War, a General Headquarters directive raised chloride concentrations to 2 ppm at purification plants for a residual concentration at the pipe-end of 0.4 ppm. This fact

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[33] The number of cities with rapid filtration for the years 1912, 1921, 1930, and 1939 were 20, 37, 84, and 188, respectively. Due to the fact that some cities introduced both slow and rapid filtration, the figures for some years exceed 100% (see Japan Society of Civil Engineers 1965, pp. 820–833).

[34] As slow-speed filtration was most common, experiments were carried out in order to increase the number of filter running days as well as filtration speed in the 1930s. For instance, experiments were conducted in Kyoto to increase the number of continuous filtration hours and reduce the frequency of dredging required from 1925. The application of this two-stage method was debated during the 1930s, but it was not introduced before the Second World War (see Japan Water Works Association 1967a, pp. 610–617). In addition, the efficiency of purification techniques to increase the speed of filtration, which was fixed at 3 meters per day, was studied in the same period (e.g., Nakada 1931).

[35] For example, Osaka guidelines stated that "adequate results can be expected if there is a residual chlorine concentration of 0.1–0.2 ppm 10 minutes after chlorine is added." (see Japan Water Works Association 1967a, pp.618). Accordingly, chlorine concentrations were set at 0.1 ppm in winter, 0.15 ppm in the fall and spring, and 0.2 ppm during the summer. However, complaints were made about the chlorine odor to the extent that chloramine disinfection was also tried, even with end-of-pipe residual chlorine concentrations of 0.1 ppm (see Japan Water Works Association 1967a, pp.618–619).

implies deficiencies of chlorine disinfection of water in prewar Japan. In summary, the most commonly used purification technology in prewar Japan was slow-speed filtration.

Appendix B Data appendix

A. Coverage of tap water and daily water consumption

In our empirical analysis, we define the coverage of tap water as the number of water taps per 100 people. The average daily water consumption per capita is defined as the total amount of annual water supply divided by both the total population and 365 days. Data on the number of water taps and water consumption are from *Jyosuido tokei oyobi hokoku* (Statistics and Reports of Water Supply; SRWS) (vol.1–21) and *Jyosuido tokei* (Statistics of Water Supply; SWS) (vol.22–31) published by the Federation of Water Authorities (1922–1932) and the Water Works Association (1934–1943). These were the national organizations composed of local municipalities that owned water-supply systems, and conducted research into waterworks technology and management. The Federation of Water Authorities was incorporated as the Water Works Association in 1932 and today, as the Japan Water Works Association, is a national body conducting research into the technology and management of water-supply systems. Population data are from *Nihon-teikoku jinkodotai tokei* (The Vital Statistics of the Empire of Japan; VSEJ) (1922–1931 editions) and *Nihon jinkodotai tokei* (The Vital Statistics of Japan; VSJ) (1932–1940 editions) published by the Statistics Bureau of the Cabinet between 1924 and 1942. Water taps include both metered and communal taps for households and business. Regarding data on annual water supply, water taps include the amount of water supply for industries, fountains, sprinklers, and street cleaning. Information on the timing of the installation of filtration technology in each city is from *Nippon Suidoshi, Kakuronhen I–III* (A History of Water Works in Japan, a detailed review I–III) published by Japan Water Works Association (1967b–1967d).

B. Mortality rates

Data on crude deaths are from the VSEJ (1922–1931 editions) and VSJ (1932–1940 editions). The number of deaths from typhoid fever from 1922 to 1927 are from the SRWS (vol.20). Data on deaths from typhoid fever after 1928 are from *Eiseikyoku nenpo* (Annual Report of the Sanitary Bureau; ARSB) (1928–1936 edition) and *Eisei nenpo* (Annual Report on Sanitation; ARS) (1937–1940 editions) published by the Sanitary Bureau of the Home Department (1930–1938), the Sanitary Bureau of the Department of Welfare (1939–1940), and the Population Bureau of the Department of Welfare (1942–1943). Data on infant deaths are from *Nihonteikoku shiin tokei* (Statistics of Causes of Death of the Empire of Japan; SCDEJ) (1922–1931 editions) and *Shiin tokei* (Statistics of Causes of Death; SCD) (1932–1936 editions) published by the Statistics Bureau of the Cabinet between 1925 and 1939. Data on infant deaths after 1937 are from the VSJ (1937–1940 editions). Data on cause-specific deaths are from the SCDEJ (1922–1931 editions) and SCD (1932–1936 editions). We supplemented the data on cause-specific deaths in 1935 and 1936 with *Hokkaidocho tokeisho* (Hokkaido Prefecture Statistics) (vol.47–48) and *Osakafu tokeisho*(Osaka Prefecture Statistics) (1935–1936 edition) published by Hokkaido Prefecture (1937–1938) and Osaka Prefecture (1937–1938), respectively.

C. Control variables

City-level age- and sex-specific population data are from *Kokusei chosa hokoku, fukenhen* (Population Census of Japan, Prefectural Part; PCJPP) (1920, 1925, 1930, and 1935 editions) published by the Statistics Bureau of the Cabinet (various years). In each census year, the PCJPP consists of 47 prefectural reports and thus, our city-level demographic data are from 184 (46 prefectures × 4 years) prefectural reports. Since the population census is conducted every 5 years in Japan, we linearly interpolate the demographic variables for noncensus years following the previous literature (e.g., Cutler and Miller 2005; Greenstone and Hanna 2014).

The number of doctors are from *Nihonteikoku tokei nenkan* (Statistical Yearbook of the Japanese Empire; SYJE) (vol.43–55) and *Dainihonteikoku tokei nenkan* (Statistical Yearbook of the Greater Japanese Empire; SYGJE) (vol.56–59) published by the Statistics Bureau of the Cabinet (1924c–1941c). The number of industrial workers are from *Kojyo tokei hyo* (Factory Statistics) (1922–1938 edition) and *Kogyo tokei hyo* (Industrial Statistics) (1939–40 editions) published by the Statistical Division of the Department of Agriculture and Commerce (1924–1926), Statistical Division of the Department of the Minister of Commerce and Industry (1927–1939), Research Division of the Department of the Minister of Commerce and Industry (1940–1941), and Research Division of the Bureau of Management and Coordination of the Ministry of Commerce and Industry (1942). Data on doctors and factories are measured at prefectural levels. The size of financial budgets in each city are from the SYJE (vol.42) and *Chiho zaisei gaiyo* (Abstract of Local Public Finance) (1923–1940) published by the Bureau of Local Affairs of the Home Department (1924–1941). Consumer price indexes are from *Nihon ginko hyakunenshi, shiryo hen* (The Hundred Year History of Bank of Japan, source materials vol.1) published by the Bank of Japan (1986, p.436).

Data on the meteorological variables, such as monthly average of the annual temperature, total amount of annual precipitation, average monthly humidity, and average monthly actual sunshine duration are downloaded from the database of the Japan Meteorological Agency. Although the meteorological observation stations are located in each city in most cases, we replicate some missing data on the observations at the nearest meteorological observing station. In the case of Naha city located in Okinawa prefecture, we cannot replicate the missing data using the nearest meteorological observation station because of long distance across the sea. The data are publicly available and can be downloaded from http://www.data.jma.go.jp/gmd/risk/obsdl/index.php.

D. Geospatial information of latitude and longitude

The data on latitude and longitude are from the database of the Geospatial Information Authority of Japan. The data are publicly available and can be downloaded from http://www.gsi.go.jp/KOKUJYOHO/kenchokan.html.

Appendix C Examples

Before conducting the empirical analysis, we provide a few examples to show the effectiveness of the popularization of clean tap water in reducing crude death rate. Figure G.6 describes the time-series plots of crude death rates and coverage of tap water in Onomichi, Mito, and Osaka city from 1922 to 1940. These three cities had introduced the modern water-supply systems at different stages of their history, and thus the coverage of tap water had increased at different paces. While Onomichi introduced the system in 1925 as shown in Figure G.6a, Mito and Osaka indeed installed the system in 1910 and 1895, respectively. Onomichi city increased the number of taps steeply, whereas Mito city had not expanded the scale of the system until 1932.

As shown in Figure G.6a, the crude death rate in Onomichi averaged about 24.9 deaths per 1,000 in the years before installing the modern water-supply system. Responding to the installation of system, the crude death rate dramatically declined by 5.9 permil, from 25.5 to 19.6 in 1925, and the rate subsequently decreased as coverage of taps increased. Mito also experienced the sharp reduction of the crude death rate in the following year of the large expansion of the system as illustrated in Figure G.6b. Although the rate in 1923 spiked due to the Great Kanto Earthquake, the rate declined by roughly 4.2 percent, from 17.9 permil in 1931 to 13.7 permil in 1933. These obvious declines in the mortality rate after the installation of the clean water technologies are highly consistent with the previous studies (e.g., Cutler and Miller 2005; Beach et al., 2016). The rate in Osaka steadily declined by the middle of 1930s as the popularization of tap water hit the ceiling around 14 taps per 100 people (see Figure G.6c).

These clear opposite trends show how the modern water-supply systems had contributed to mitigate in the mortality risks of the various cities in the 1920s and 1930s. In the following sections, we present more comprehensive evidences of the impact of modern water-supply systems using a unique city-level panel dataset beyond the examples of three cities that described above.

Appendix D Aspects of water consumption

Since the amount of available water directly affects the standard of public health in the city, especially when the quantity of piped water is below the minimum requirement of water, the likelihood of contracting diseases should depend on the average per capita daily water use in the city. In fact, the risk of waterborne infectious diseases transmitted through the fecal–oral route is linked to the poor quantity of water consumption and thus, personal hygiene levels improve if an adequate quantity of clean water can be used (e.g., Cairncross and Feachem 1993). More generally, maintaining an adequate hydration level is necessary for humans to maintain life (e.g., Gleick 1996; White et al., 1972). Therefore, we expect that the effect of modern water-supply systems is more remarkable in the cities in which people can use enough water to prevent infectious diseases.

As a measurement of the quantity of water, we use the average daily water consumption per capita (*Consumption*), which is defined as the total amount of annual water supply divided by both total population and 365 days. The mean average daily water consumption is approximately is 26.3 liters. The data sources for this variable are the SRWS and SWS. In our flexible estimates, we consider the interaction term between the coverage of tap water and average daily water consumption per capita ($Consumption_{it}$). Our flexible model is then given by

$$\begin{aligned} y_{it} = \alpha + \delta_1 \, Water_{it} \; &+ \; \delta_2 \, Water_{it} \cdot Consumption_{it} + \mathbf{x}'_{it}\boldsymbol{\beta} \\ &+ \; \sum_{c=2}^{108} \gamma_c I_{ci} + \sum_{j=1923}^{1940} \rho_j I_{jt} + t \sum_{c=2}^{108} \mu_c I_{ci} + e_{it} \end{aligned} \tag{3}$$

We expect that both δ_1 and δ_2 are estimated to be negative. In addition, we estimate a flexible specification in which the covariates $\mathbf{x}'_{it}$ are replaced with the covariates that multiply the period dummy $\mathbf{x}'_{it}\boldsymbol{I}_t^{1930s}$, which is the same as our baseline model. Note that the average daily water consumption per capita was directly depended on the capacity of water supply, and thus was greatly influenced by the uncertainties in the process of the expansion projects in each city.

Table G.11 presents the results of our flexible model. The estimated coefficient on the interaction term tends to be negative, but does has no significant impact on the mortality rates. The results are robust to controlling for allowing the coefficients to vary across periods. These results confirm that the effect of the coverage of tap water did not depend on or vary with the amount of daily water consumption. It is confirmed that this result is unchanged across all specifications which are reported in the following part of this paper.

The insignificant effect of the quantity of water can be explained using the following reason. As we noted, the mean average daily water consumption is approximately 26.3 liters a day in our sample. This value becomes 33.4 liters when we do not account for cities that have not installed waterworks. Correspondingly, the World Health Organization (2003, pp.6–9) estimates that the basic minimum required for drinking water and foodstuff preparation is 4.2 liters per day for adult females, 4.9 liters per day for adult males, and 7.5 liters per day for lactating women. Moreover, at least 20 liters per day are required to ensure basic hygiene (World Health Organization 2003, executive summary and pp.22–23). In general, the available quantity of water collected decreases steeply if the time taken to collect water exceeds a few minutes (World Health Organization 2003, p.18). In our case, however, family members were able to access water immediately because clean water was piped into the home through a tap. Therefore, from the viewpoint of water quantity, the modern water-supply systems in prewar Japan satisfied the requirements for humans to maintain adequate hydration levels, including cooking, and met the criteria of basic requirements for personal hygiene.

We should also point out other possibilities of these results. The total amount of annual water supply does not include the value from the usage of fire hydrants, whereas the amount of water supply for industries, fountains, sprinklers, and street cleaning might be included (Hirose 1951, p.13). This means that our measurement of water quantity includes the water consumption for all domestic purposes, such as drinking, cooking, personal washing, washing clothes, and bathing, as well as other purposes, such as industry, commerce, street cleaning, and recreation. Since domestic water consumption typically constitutes a minor component of total water withdrawals (e.g., Gleick 1996), there might be a measurement error in our analysis when we include this measure of the amount of daily water consumption. Therefore, although it is less than conclusive, we argue that the improvement of water quality is more likely to an important factor in mitigating the mortality rate than the improvement of water quantity in 1920s and 1930s Japan.

Appendix E Interpretation of the results for the infant mortality rate

As shown in Section 4.1, the magnitude of the estimated effect on the infant mortality rate is smaller than the crude death rate: roughly 14% of the total improvement of the infant mortality rate is associated with the popularization of tap water. This estimate is considered reasonable for the following reasons. First, as a rule, the infants themselves did not drink or use tap water and thus, the improvement of water quality did not affect their personal hygiene level directly. Moreover, the reduction of health risk for infants depended on their parents' knowledge, attitude, or even altruism (e.g., Loomis et al., 2009). Second, clean water should have been effective if the parents used artificial feeding, such as milk other than the mother's instead of breast-feeding, as water would have been used when diluting milk or washing the feeding bottle. However, a pediatrician reported that the quality of milk was considerably low due to lack of refrigerators and time-consuming delivery (Ohota 1925, pp.36–40). This means that improving water quality might have been less effective in the case of artificial feeding than the case of washing the feeding bottle. Third, weaning was usually conducted after a child's first birthday in prewar Japan (Ohota 1925, p.62). Thus, infants were less likely to be exposed to semisolid or solid foods or to drinking water, by which any pathogens or viruses were possibly transmitted, and thus, clean water is considered effective.

Finally, the disparities in the magnitude of estimated effects between the crude and infant death rates can also be explained in terms of the evidence in immunology that transferable maternal immunologic memory is indispensable for the survival of infants. Infants incapable of producing immunoglobulins (Ig) are protected by maternal antibodies for the first 3–12 months after birth even in the case of early weaning: maternal IgG antibodies enter fetal circulation through the placenta and IgA antibodies in milk remain larger within an infant's gut, where they influence the intestinal flora (Zinkernagel 2001, pp.1331–1332). Since maternal protection influences infections with not only typical pathogens but also gastrointestinal and respiratory viruses (Zinkernagel 2001, p.1333), clean water would be less important to inhibit infectious risks.

The abovementioned historical and immunological facts suggest that indirectly improving the effects of clean water through improving personal hygiene of parents or family members is considered more important for reducing the risk of infant deaths than the direct effects. Therefore, we argue that clean water via modern water-supply systems might have contributed to reducing the risk of deaths of children aged more than 13 months rather than infant deaths because maternal protection disappeared after the infancy period and because infants experienced the first exposure to any threats.

Appendix F Procedure for calculating benefit of modern water-supply systems

The overall benefits of the modern water-supply systems are calculated as follows. First, we estimate the number of people saved by the modern water-supply system in each city and year. As reported in Table 10, the estimated coefficient on the coverage of tap water in our baseline estimate is -0.1664, and the 95% confidence intervals are [-

0.0168, -0.3160] (see column (4) of Table 4). For each city and year, multiplying the product term between this point estimate and the coverage of tap water and the population size, we yield the number of people saved by the modern water-supply systems. In this calculation, we assume that the effect of the popularization of tap water did not vary by either population size or the initial tap water coverage rates. The results in Section 4.2 support this assumption. As shown in the second row of table, the average number of people saved per year in our sample cities is estimated to be 23,967.

Second, we convert lives saved into person-years saved using the age of death due to waterborne infectious diseases, including typhoid fever, dysentery, and diarrhea. This assumption is plausible because the modern waterworks mainly improved water-related deaths but not deaths from respiratory infectious diseases. Specifically, we compile data on both the number of waterborne deaths by sex and age group in Japan between 1922 and 1940 and on life expectancy by sex and age group in 1930 (e.g., the number of waterborne deaths was 991,409 and life expectancy was 46.54 at birth for males). [36] Using these data, we calculate the average life expectancy of people who would have died if they had not received any benefit from the waterworks. As reported in the third row of Table 10, the average life expectancy was 40.2 years, which we can attribute to clean water per person. As a result, the average person-years saved are calculated as approximately 1 million people per year (see the fourth row).

Third, we estimate the value of person-years at that time. Following Cutler and Miller (2005), we assume that a reasonable value of a person-year in 2003 was about 100,000 dollars on average (Viscusi and Aldy 2003) and, for simplicity, that the value of a person does not vary with age. Hence, in 2014 dollars, the average value of a person-year in 2003 is 128,660 dollars. [37] Similarly, we assume that the elasticity of the value of life with respect to the per capita gross national product to range from 1.5 to 1.7 (Costa and Kahn 2002). Since the gross domestic product per capita was 1,850 Geary–Khamis dollars in Japan in 1930 and 29,459 Geary–Khamis dollars in the United States in 2003, the value of person-years in Japan in 1930 is conservatively estimated as 4,753 in 2014 dollars (see

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[36] The data on life expectancy are taken from the Statistics Bureau of the Cabinet (1936).

[37] The consumer price index for all urban consumers (CPI-U) was 184 in 2003 and 236.736 in 2014, respectively. The CPI-U data are publicly available at the website of the Bureau of Labor Statistics, United States Department of Labor (http://www.bls.gov/cpi/). We use Table 24 of the CPI Detailed Report Data for September 2015 for our calculation.

fifth row of table). [38] Finally, the average overall benefits of the modern waterworks are estimated as 4,546 million dollars, and the 95% confidence intervals are [462, 8690] (see sixth row of table).

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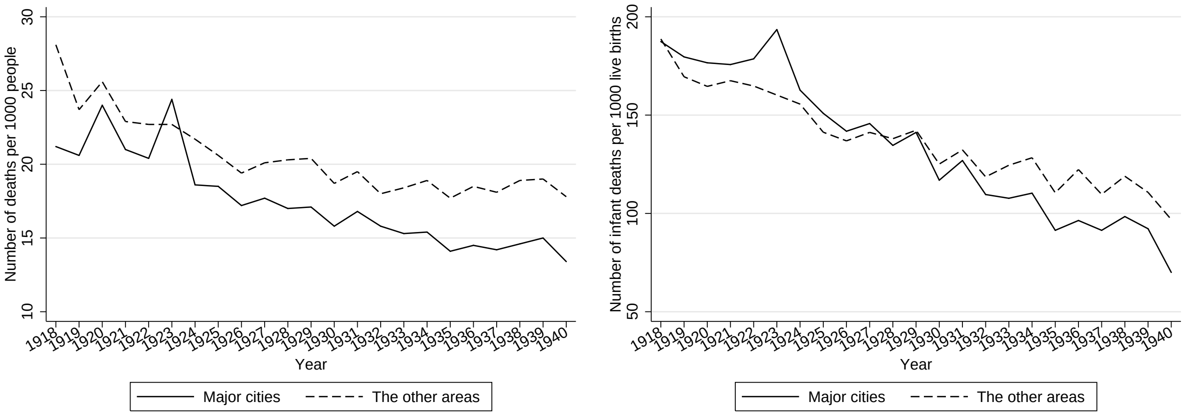
[38] The data on the gross domestic product per capita in 1990 Geary–Khamis dollars are obtained from the database of The Maddison Project, http://www.ggdc.net/maddison/maddison-project/home.htm, 2013 version.

Appendix G Additional Figures and Tables

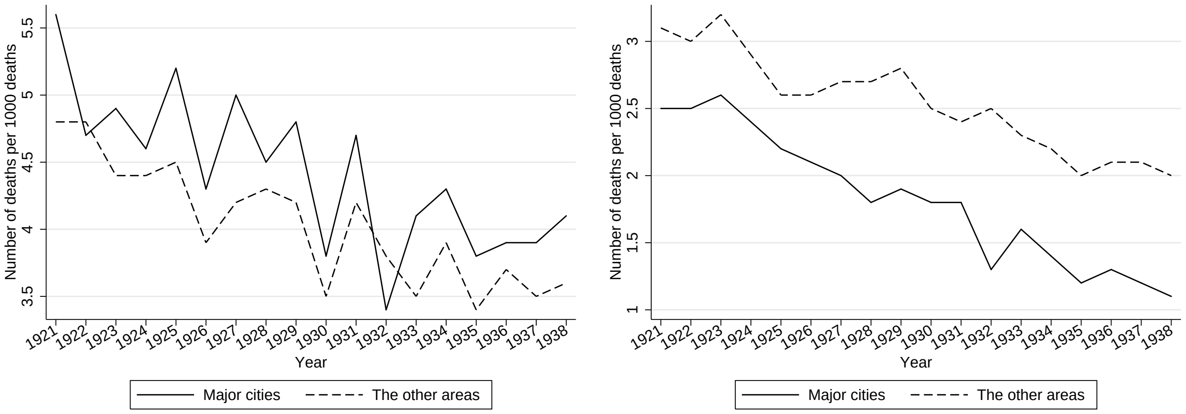


(a) Crude death rate

(b) Infant mortality rate

Figure G.1: Crude death rate and infant mortality rate

Note: Major cities include those each with a population of more than 100,000. The soar in the mortality rate in 1923 is caused by the Great Kanto Earthquake. Source: Statistics and Information Department, Minister's Secretariat, Ministry of Health and Welfare (1999, pp.84–85); Statistics Bureau of the Cabinet (1924a–1942a).

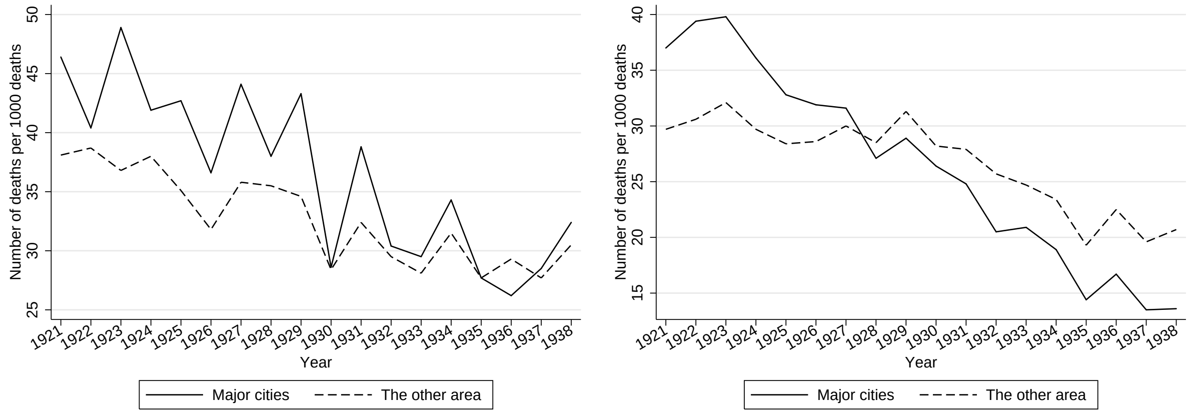


(a) Respiratory infections

(b) Gastrointestinal infections

Figure G.2: Number of deaths attributed to infectious diseases per 1,000 people

Note: Major cities include those each with a population of more than 100,000. Source: Statistics and Information Department, Minister's Secretariat, Ministry of Health and Welfare (1999, pp.84–85); Statistics Bureau of the Cabinet (1924a–1942a).

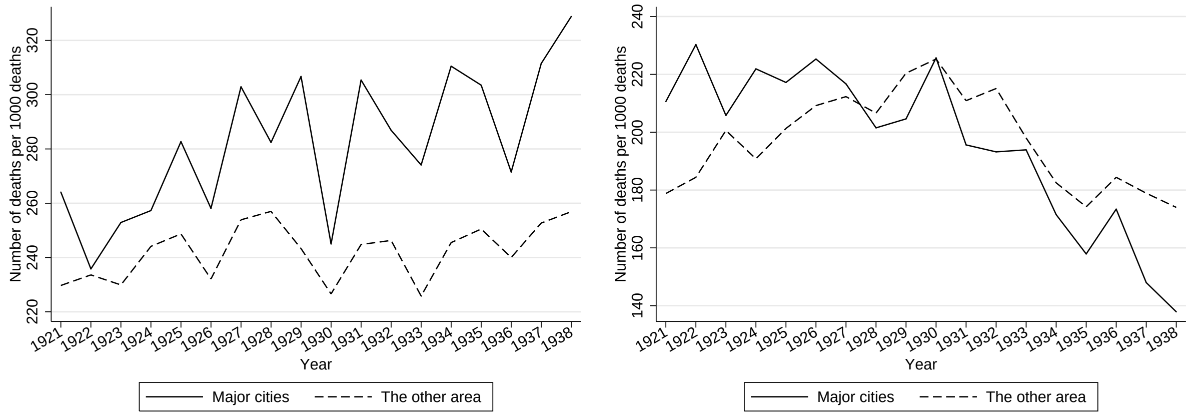


(a) Respiratory infections

(b) Gastrointestinal infections

Figure G.3: Number of infant deaths attributed to infectious diseases per 1,000 live births

Note: Major cities include those each with a population of more than 100,000. Source: Statistics and Information Department, Minister's Secretariat, Ministry of Health and Welfare (1999, pp.84–85); Statistics Bureau of the Cabinet (1924a–1942a).

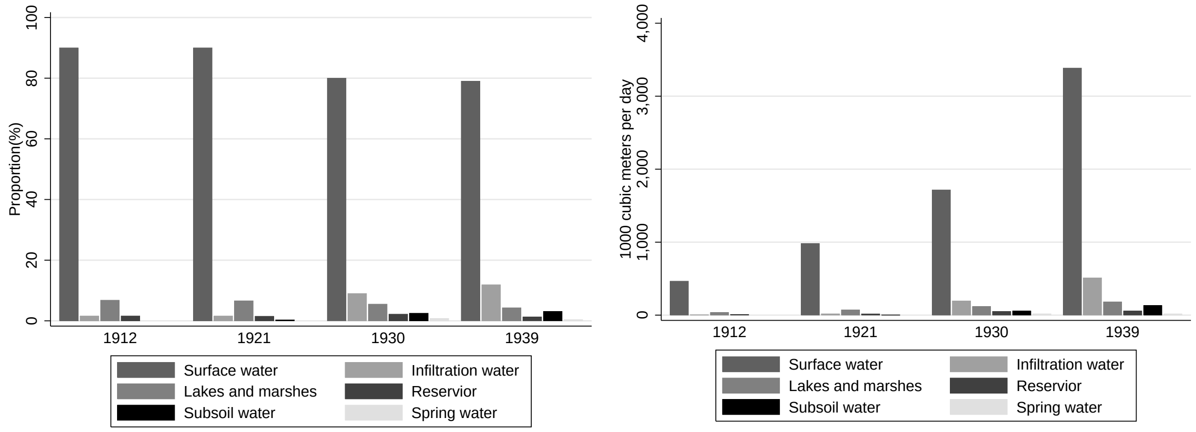


(a) Respiratory infectious diseases

(b) Gastrointestinal infectious diseases

Figure G.4: Number of infant deaths attributed to infectious diseases per 1,000 infant deaths

Note: Major cities include those with a population lager than 100,000. The fall in the ratio of respiratory infectious diseases in major cities in 1930 reflects the epidemic of diarrhea and enteritis, as shown in (b). Source: Statistics Bureau of the Cabinet (1924b–1939b).

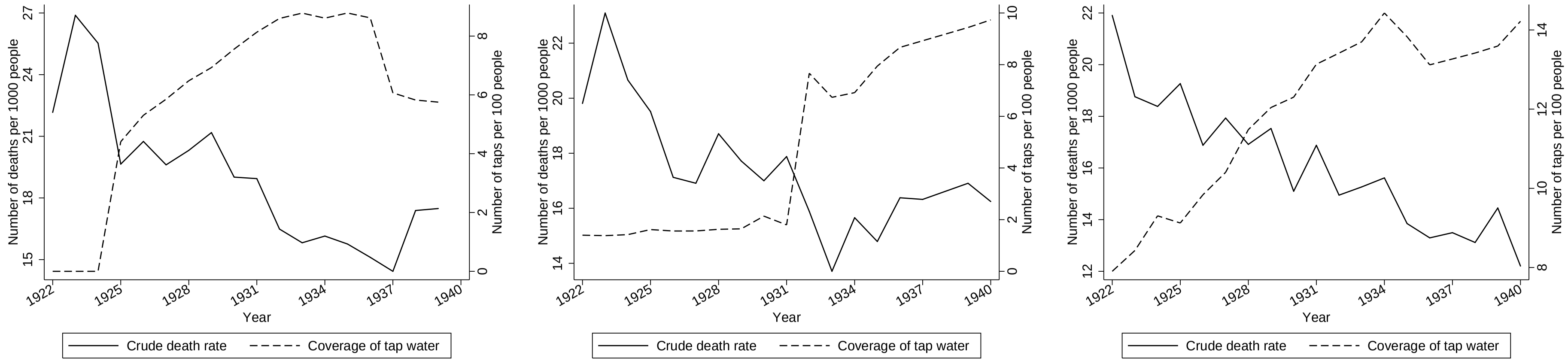


(a) Proportion of water sources (%)

(b) Total amount of water per day (1,000 m^3)

Figure G.5: Proportion of water sources and total amount of water per day

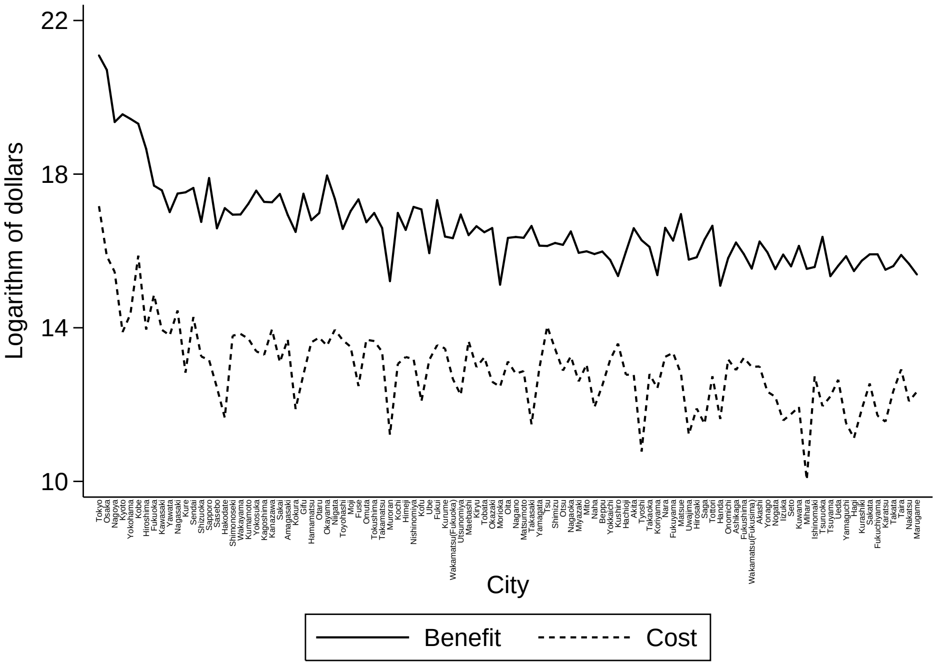
Note: Number of cities in 1912, 1921, 1930, and 1939 are 18, 36, 86, and 115, respectively. Source: Japan Society of Civil Engineers (1965, pp.812–813).



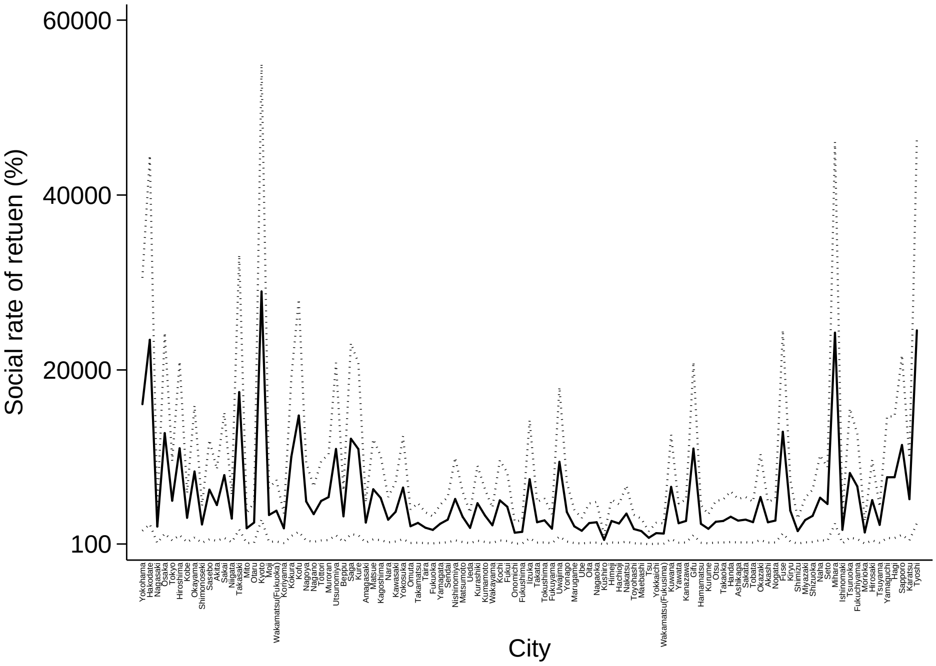
(a) Onomichi (b) Mito (c) Osaka

Figure G.6: Crude death rates and coverage of tap water in Onomichi, Mito, and Osaka city

Note: Crude death rate is the number of deaths per 1,000 people. Coverage of tap water is the number of water taps per 100 people. *Source*: Statistics Bureau of the Cabinet (1924a–1932a), Statistics Bureau of the Cabinet (1934a–1942a), Federation of Water Authorities (1922–1932), and Water Works Association (1934–1943).



(a) Benefit and cost in the sample cities



(b) Social rate of return in the sample cities ordered by install year

Figure G.7: Benefit, cost, and social rate of return in the sample cities

Note: Both benefits and costs are the average annual benefits and costs of the modern water-supply systems in our sample cities. Aomori, Ichinomiya, and Matsuyama cities are excluded due to missing cost values. Sample cities are arranged in order of the timing of the installation of the modern water-supply systems.

Table G.1: Number of deaths attributed to major infectious diseases per 1,000 deaths

	Major cities					The other areas				
Cause of death	1921	1925	1929	1933	1938	1921	1925	1929	1933	1938
Respiratory infections	264.9	279.1	280.8	265.2	275.9	208.5	221.0	204.2	189.6	195.0
Influenza	7.8	5.8	7.0	3.6	4.6	8.0	9.4	6.7	4.1	6.0
Whooping cough	6.6	9.2	9.9	5.0	10.1	5.2	6.7	7.4	5.2	6.2
Measles	18.0	23.8	27.8	14.7	3.5	9.9	11.2	10.3	5.2	4.1
Diphtheria	4.1	4.7	5.6	7.6	4.8	2.9	2.7	3.4	3.8	2.9
Scarlet fever	0.3	0.7	0.5	1.0	0.8	0.0	0.2	0.2	0.2	0.2
Tuberculosis	104.9	100.4	106.1	123.7	130.8	59.2	62.7	64.3	67.2	72.1
Pneumonia and bronchitis	123.2	134.5	123.9	109.6	121.3	129.3	136.2	120.9	110.4	112.6
Gastrointestinal infections	121.1	119.6	110.8	102.5	78.2	134.1	128.9	136.9	123.0	110.7
Diarrhea and enteritis	100.4	98.9	94.7	80.7	57.7	122.5	120.0	129.0	69.6	50.8
Typhoid fever	16.4	16.4	10.9	12.2	10.0	9.0	7.1	5.6	5.0	5.1
Dysentery	4.3	3.9	5.0	9.6	10.5	2.6	1.4	2.1	1.4	2.6
Cholera	0.0	0.4	0.2	0.0	0.0	0.0	0.3	0.1	0.0	0.0

Note: Major cities include those each with a population of more than 100,000. In 1930, for example, these included Sapporo, Otaru, Hakodate, Sendai, Tokyo, Yokohama, Kanazawa, Nagoya, Kyoto, Osaka, Sakai, Kobe, Okayama, Hiroshima, Kure, Fukuoka, Yahata, Nagasaki, Kumamoto, and Kagoshima. Pneumonia and bronchitis include both acute bronchitis and chronic bronchitis. *Source*: Statistics Bureau of the Cabinet (1924b–1939b).

Table G.2: Number of infant deaths attributed to major infectious diseases per 1,000 infant deaths

	Major cities					The other areas				
Cause of death	1921	1925	1929	1933	1938	1921	1925	1929	1933	1938
Respiratory infections	264.1	282.7	306.7	274.1	328.8	229.7	248.7	243.3	225.8	256.9
Influenza	3.7	4.9	8.4	5.1	10.7	4.7	8.0	7.3	5.4	9.2
Whooping cough	14.2	20.4	22.8	14.3	35.7	11.3	14.8	17.0	13.2	18.3
Measles	25.1	33.0	46.5	30.8	9.1	10.9	13.0	14.0	8.1	7.5
Diphtheria	1.5	1.5	2.1	3.4	2.9	1.1	0.8	0.8	0.9	1.1
Scarlet fever	0.0	0.1	0.1	0.2	0.4	0.0	0.0	0.0	0.0	0.0
Tuberculosis	2.6	2.8	3.0	3.0	4.3	2.1	2.1	2.1	1.5	1.7
Pneumonia and bronchitis	217.0	220.0	223.8	217.3	265.8	199.6	210.0	202.1	196.6	219.0
Gastrointestinal infections	210.6	217.2	204.6	193.9	137.9	178.8	201.3	220.4	198.0	174.0
Diarrhea and enteritis	210.3	216.9	204.4	193.2	136.9	178.6	201.1	220.2	197.9	173.9
Typhoid fever	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0
Dysentery	0.2	0.2	0.1	0.6	0.9	0.1	0.1	0.1	0.1	0.1
Cholera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: Infants are defined as children aged from birth to 12 months. Major cities include those each with a population of more than 100,000. In 1930, for example, these included Sapporo, Otaru, Hakodate, Sendai, Tokyo, Yokohama, Kanazawa, Nagoya, Kyoto, Osaka, Sakai, Kobe, Okayama, Hiroshima, Kure, Fukuoka, Yahata, Nagasaki, Kumamoto, and Kagoshima. Pneumonia and bronchitis include both acute bronchitis and chronic bronchitis. *Source*: Statistics Bureau of the Cabinet (1924b–1939b).

Table G.3: Number of deaths attributed to major infectious diseases per 1,000 people

	Major cities					The other areas				
Cause of death	1921	1925	1929	1933	1938	1921	1925	1929	1933	1938
Respiratory infections	5.6	5.2	4.8	4.1	4.1	4.8	4.5	4.2	3.5	3.6
Influenza	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1
Whooping cough	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Measles	0.4	0.4	0.5	0.2	0.1	0.2	0.2	0.2	0.1	0.1
Diphtheria	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Scarlet fever	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tuberculosis	2.2	1.9	1.8	1.9	1.9	1.4	1.3	1.3	1.2	1.3
Pneumonia and bronchitis	2.6	2.5	2.1	1.7	1.8	2.0	2.2	1.9	1.6	1.7
Gastrointestinal infections	4.7	4.0	3.5	2.8	2.0	3.1	2.6	2.8	2.3	2.0
Diarrhea and enteritis	2.1	1.8	1.6	1.2	0.8	2.8	2.5	2.7	2.2	1.9
Typhoid fever	0.3	0.3	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1
Dysentery	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.0
Cholera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: Major cities include those each with a population of more than 100,000. In 1930, for example, these included Sapporo, Otaru, Hakodate, Sendai, Tokyo, Yokohama, Kanazawa, Nagoya, Kyoto, Osaka, Sakai, Kobe, Okayama, Hiroshima, Kure, Fukuoka, Yahata, Nagasaki, Kumamoto, and Kagoshima. Pneumonia and bronchitis include both acute bronchitis and chronic bronchitis. *Source*: Statistics Bureau of the Cabinet (1924b–1939b).

Table G.4: Number of infant deaths attributed to major infectious diseases per 1,000 live births

	Major cities					The other areas				
Cause of death	1921	1925	1929	1933	1938	1921	1925	1929	1933	1938
Respiratory infections	46.4	42.7	43.3	29.5	32.4	38.1	35.1	34.6	28.1	30.5
Influenza	0.7	0.7	1.2	0.5	1.1	0.8	1.1	1.0	0.7	1.1
Whooping cough	2.5	3.1	3.2	1.5	3.5	1.9	2.1	2.4	1.6	2.2
Measles	4.4	5.0	6.6	3.3	0.9	1.8	1.8	2.0	1.0	0.9
Diphtheria	0.3	0.2	0.3	0.4	0.3	0.2	0.1	0.1	0.1	0.1
Scarlet fever	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tuberculosis	0.5	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.2	0.2
Pneumonia and bronchitis	38.1	33.2	31.6	23.4	26.2	33.1	29.7	28.7	24.5	26.0
Gastrointestinal infections	37.0	32.8	28.9	20.9	13.6	29.7	28.4	31.3	24.7	20.7
Diarrhea and enteritis	36.9	32.7	28.9	20.8	13.5	29.6	28.4	31.3	24.6	20.7
Typhoid fever	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dysentery	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Cholera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: Infants are defined as children aged from birth to 12 months. Major cities include those each with a population of more than than 100,000 people. In 1930, for example, these included Sapporo, Otaru, Hakodate, Sendai, Tokyo, Yokohama, Kanazawa, Nagoya, Kyoto, Osaka, Sakai, Kobe, Okayama, Hiroshima, Kure, Fukuoka, Yahata, Nagasaki, Kumamoto, and Kagoshima. Pneumonia and bronchitis include both acute bronchitis and chronic bronchitis. *Source*: Statistics Bureau of the Cabinet (1924b–1939b).

Table G.5: Causes and uncertainties of modern water-supply projects before 1918: typical examples

List of cities	Start of the plan	Ground -breaking	Installation (Commencement)	Main factor of the installation	Uncertainties of the installation	Uncertainties of the expansion
Muroran	1902	1915	1916	Decline in groundwater level	Water rights issue	Changes in the water source, expansion plan of steelworks, outbreak of WWII
Akita	1889	1903	1911	Deterioration of water quality, big fire, epidemic of infectious disease, flood, outbreak of Sino–Japanese War, installation of military base, demand of water supply for railway steam engines	Government subsidy application failure, outbreak of Russo–Japanese War, consolidation of municipalities, flood	Deterioration of facilities, outbreak of WWII
Tokyo	1874	1892	1899	Deterioration of old water-supply system, fire prevention	Securing revenues, design change, land acquisition, outbreak of Sino–Japanese War	Outbreak of WWI, First and Second Sino–Japanese Wars, WWII, Great Kanto Earthquake, population growth, depletion of water source, water rights issue
Kofu	1890	1910	1912	Poor groundwater quality and groundwater shortage due to geographical feature, deterioration of the old water-supply system	Outbreak of Sino–Japanese War and Russo–Japanese War, economic depression, water rights issue, opening of railway, failure of water-source investigation, flood, residents' opposition	Great Kanto Earthquake, conflicting views at assembly, coastal residents' opposition
Nagano	1873	1913	1914	Groundwater shortage and poor groundwater quality due to geographical feature, drought during winter	Disagreement about investment at community association, dissolution of community association, outbreak of Russo–Japanese War	Water rights issues, opposition to expansion works of water source
Nagoya	1891	1910	1914	Poor well-water quality and well-water shortage due to geographical feature, Nobi Earthquake	Financial problems, outbreak of Russo–Japanese War, delay of land acquisition	Decline in water pressure, deterioration of aqueduct, change in flow of water source, outbreak of Second Sino–Japanese War, WWI, and WWII
Kyoto	1889	1909	1912	Poor well-water quality due to geographical feature, well-water shortage due to deforestation	Deficiency of flow in water source, geological survey	Consolidation of municipalities, flood, integration of water-supply system for military, outbreak of WWII
Osaka	1890	1892	1895	Big fire, poor well-water quality due to geographical feature, deterioration of river water due to factory construction	Reduction in estimated value of government subsidy, revision in annual expenditure	Outbreak of Sino–Japanese War, Second Sino–Japanese War, WWI, and WWII, plague epidemic, land acquisition problem, Muroto typhoon, water rights issues
Sakai	1900	1908	1910	Poor well-water quality, drought in summer	Financial problems, outbreak of Russo–Japanese War, confrontation between political parties in city council	Water quality survey, outbreak of WWII, Muroto typhoon
Kobe	1887	1897	1900	Water shortage due to geographical feature, epidemic of infectious disease, contamination of well water	Confrontation between political parties in ward assembly, dissolution of imperial diet, outbreak of Sino–Japanese War, changes in laying plan	Consolidation of municipalities, outbreak of WWI and WWII, typhoon, opposition by farmers, drought
Tottori	1903	1912	1915	Poor well-water quality due to geographical feature, deterioration of old water-supply system, big fire	Financial problems, donation	Flood, opposition by residents, earthquake
Matsue	1895	1914	1919	Poor well-water quality due to geographical feature	Financial problems, changes in laying plan, outbreak of Russo–Japanese War and WWI, land acquisition, heavy snowfall	Drought, flood, outbreak of WWII, rupture of lead pipe due to cold air mass

List of cities	Start of the plan	Ground -breaking	Installation (Commencement)	Main factor of the installation	Uncertainties of the installation	Uncertainties of the expansion
Hiroshima	1894	1896	1898	Poor well-water quality due to geographical feature	Outbreak of Sino–Japanese War, laying of water supply for military, revision in laying plan	Earthquake, drought, outbreak of Russo–Japanese War, WWI, and WWII
Kure	1902	1915	1918	Poor well-water quality due to geographical feature	Application of military water-supply system, application of water supply for military, dissolution of the Diet, outbreak of WWI	Changing the water source, residents' opposition, resignation of city mayor, resignation of all city council members, outbreak of WWII
Shimonoseki	1891	1901	1906	Infiltration of seawater into well water	Outbreak of Sino–Japanese War, water rights issues, land acquisition	Rapid flow of tide, frequent traffic of ships, outbreak of Second Sino–Japanese War, WWI, and WWII
Kokura	1906	1910	1913	Poor well-water quality due to geographical feature	Outbreak of Russo–Japanese War, investigation of water-source area	Consolidation of municipalities, drought in summer, outbreak of WWII
Moji	1892	1910	1912	Poor well-water quality due to geographical feature, water shortage due to population growth	Opposition by residents in water-source area, conflicting views at city council, water rights issues, outbreak of Russo–Japanese War	Compensation of water rights, land acquisition, financial arrangements, consolidation of municipalities, water rights issues
Nagasaki	1886	1889	1891	Limited water source and poor well-water quality due to geographical feature, deterioration of old water-supply system, demand for foreign settlement	Approval of government subsidy, conflicting views in ward council	Opposition movement, big fire, consolidation of municipalities, drought, increase in price, investigation of new water-source area, outbreak of WWII

Note: The cities listed above are municipalities in our samples with representative reasons in the installation and typical uncertainties in the process of expansion projects. The cities listed above include towns that installed modern water-supply systems before 1918 and were reorganized as cities before 1940. *Sources*: Japan Water Works Association (1967b, 1967c, 1967d).

Table G.6: Agreed Testing Methods

Test Item	Details
Sampling Methods	Sampling will be carried out as follows: 1. Water sources will be tested for quality at an appropriate location twice per year, in spring and fall. ·Extra testing may be carried out as required ·Water sources with depositing reservoirs should apply the following: 1. Purification plants, filtration ponds, holding ponds, and reservoirs should be tested daily. Weekly testing may be permitted under special circumstances. ·Where filtration ponds, holding ponds, and purification ponds are located in remote areas, supply taps should be managed as per the following: 1. Tap sections should be inspected occasionally. Water intake apparatus should utilize either Hyroht or Esmarch techniques. However, for bacteriological testing, the entire apparatus attached to the bottle should be disinfected. Samples from filtration ponds, holding ponds, and purification ponds must be taken from the center of the pond and middle depth. When taking a sample from a tap, the tap should be allowed to run for at least 5 minutes prior to taking the sample. When taking samples from a fixed location, samples for bacteriological testing should be taken first, followed by those for chemical testing. In the event of rain at covered locations at filtration ponds, holding ponds, and purification ponds, polluted water may become contaminated with dirty water once coverings are removed. For this reason, samples should be taken after waiting for water qualities to return to an average range. Water temperature should be measured using a Pettenkofer water temperature gauge. Air temperature should be measured close to where the water sample is taken, avoiding direct sunlight. Water temperature should be measured using a Pettenkofer water temperature gauge. Air temperature should be measured close to where the water sample is taken, avoiding direct sunlight. Sufficient measurement times should be taken, with degrees registered in Celsius.
Physical and chemical testing	Temperature, turbidity, chromaticity, odor, reactions, chlorine levels, sulfuric acid, nitric acid, nitrous acid, ammonia, protein ammonia level, nitrogen assays, potassium permanganate consumption amount, hardness, evaporated residues, lead, iron.
Bacteriological testing	Testing devices, culture materials, culture preparation, collection, and conservation of water samples, flat-plate culture cultivation, colony-unit estimation techniques.
Suitability for drinking	Water with any of the characteristics shown below is not suitable for drinking and requires immediate remedial measures. In the meantime, it must be boiled prior to consumption. 1. An abnormal appearance 1. An abnormal smell or taste 1. Immediately reacts for nitrous acid or ammonia. 1. A potassium permanganate decolonization amount above 10 mg. 1. More than 100 bacterial colonies. 1. Abnormal reactions, hardness, or levels of chloride, sulfuric acid, and total residues. Water with detected levels of lead should be assessed for quality as appropriate. Where water is suspected to contain abnormal substances or pathogenic bacteria, testing must be carried out and suitable remediation measures taken.

Note: Testing methods used for each item of chemical and bacteriological testing have been omitted. Methodologies for physical/chemical testing and bacteriological testing were partially revised at the general meeting of the Federation of Water Authorities in 1926, and were renamed as the Agreed Waterworks Testing Methods (Federation of Water Authorities 1923, pp.10–19). This revision added techniques for measuring temperature and iron levels, and methods to test for alkalinity, chloride, nitrous acid, and potassium permanganate consumption were changed. For bacteriological tests, revisions changed the medium for culture cultivation, from a gelatin to an agar medium. In addition to adding a technique for estimating amounts of Escherichia coli (E. coli) using Endo agar, E. coli testing methods were added in a supplementary clause (Japan Water Works Association 1967a, p.697). From the mid-1920s, the federation carried out biological research on water-supply systems, and in the 1930s, the Water Works Association (renamed from the Federation of Water Authorities in 1932) published biological studies on waterworks in its magazine. The 1936 general meeting of the Water Works Association agreed to adopt the Water Works Association Agreed Waterworks Testing Methods, a revision of the previous common methods, and techniques for biological testing were added in 1940.
Source: Japan Water Works Association (1967a, p.695); Federation of Water Authorities (1928, pp.11–39)

Table G.7: Summary statistics

	Observations	Mean	Std.Dev.	Min	Max
Baseline controls					
Demographic controls					
Population (ln transformation)	1649	11.38	0.92	10.00	15.73
Share of population aged 0–14 years (percentage points)	1649	33.81	2.53	27.21	43.53
Share of population aged 15–24 years (percentage points)	1649	22.32	2.74	11.25	33.17
Share of population aged 25–59 years (percentage points)	1649	38.02	2.00	32.62	43.71
Share of population aged 60+ years (percentage points) (reference group)	1649	5.85	1.31	3.13	10.50
Socioeconomic controls					
Coverage of doctors (percentage points)	1649	0.75	0.24	0.06	2.15
Proportion of factory workers (percentage points)	1643	3.47	2.41	0.13	12.47
Revenue per capita (yen) (ln transformation)	1645	2.75	0.51	0.48	4.90
Additional controls					
Demographic controls					
Sex ratio of population aged 0–14 years	1649	0.99	0.06	0.52	1.42
Sex ratio of population aged 15–24 years	1649	1.03	0.23	0.12	1.83
Sex ratio of population aged 25–59 years	1649	0.96	0.10	0.66	1.29
Sex ratio of population aged 60+ years	1649	1.36	0.16	0.71	2.36
Meteorological variables					
Average monthly temperature (Celsius)	1648	13.83	2.39	4.28	22.53
Total amount of annual precipitation (millimeters)	1648	1519.04	464.77	578.20	3656.40
Average monthly humidity (percentage points)	1648	75.21	3.06	67.50	85.75
Average monthly actual sunshine duration (hours)	1648	176.80	19.76	121.86	232.45
Period dummy (1931–1940)	1649	0.54	0.50	0.00	1.00

Notes: *Coverage of doctors* and *Proportion of factory workers* are the prefectural-year level variables. All the other variables are city-year level variables. *Coverage of doctors* is the number of doctors per 100 people. *Proportion of factory workers* is the number of factory workers per 100 people. *Revenue* is the natural logarithm of the total annual revenue per capita (yen). *Sex ratio* is the number of women divided by the number of men. *Period dummy* is an indicator that equals one for periods after 1931.

Table G.8: Clustering standard errors at prefectural level

	Crude death rate			Typhoid death rate			Infant mortality rate		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Water	-0.166**	1.371	-0.108	-0.009*	0.029	-0.010*	-1.216**	1.577	-0.963*
	(0.074)	(1.186)	(0.068)	(0.005)	(0.046)	(0.005)	(0.474)	(5.982)	(0.571)
Water×*Population*		-0.135			-0.003			-0.221	
		(0.108)			(0.004)			(0.472)	
Water×*Consumption*			-0.002			0.000			-0.006
			(0.001)			(0.000)			(0.007)
Baseline controls									
Demographic controls (×period dummy)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic controls (×period dummy)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F-statistic p-value on joint significance of baseline controls	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0008	0.0000
Fixed effects									
City- and Year- fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.8262	0.8259	0.8293	0.5282	0.5287	0.5302	0.8971	0.8972	0.8962
Number of clusters	108	108	108	108	108	108	104	104	102
Number of observations	1639	1639	1596	1416	1416	1377	656	656	648

Notes: Observations are at the city-year level. Dependent variables are any one of the crude death rate, typhoid death rate, and infant mortality rate. Crude death rate is the number of deaths per 1,000 people. Typhoid death rate is the number of deaths from typhoid fever per 1,000 people. Infant mortality rate is the number of infant deaths per 1,000 live births. *Water* is the number of water taps per 100 total population. Demographic controls include the natural logarithm of the total population and shares of population aged 0–14, 15–24, and 25–59 years. Socioeconomic controls include the natural logarithm of total revenue, number of doctors per 100 people, and proportion of factory workers per 100 people. Period dummy is an indicator variable that equals one for periods after 1931. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors in parentheses are clustered by prefecture (45 prefectures in total).

Table G.9: Estimation results for dynamic panel data model

	Crude death rate		Typhoid death rate		Infant mortality rate	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Water	-0.194**	(0.091)	-0.009*	(0.005)	-1.444*	(0.759)
Crude death rate$_{t-1}$	-0.041	(0.052)				
Typhoid death rate$_{t-1}$			0.084	(0.054)		
Infant mortality rate$_{t-1}$					-0.512***	(0.069)
Baseline controls						
Demographic controls (×period dummy)	Yes		Yes		Yes	
Socioeconomic controls (×period dummy)	Yes		Yes		Yes	
F-statistic p-value on joint significance of baseline controls	0.0000		0.0144		0.0000	
Fixed effects						
City- and Year- fixed effects	Yes		Yes		Yes	
City fixed effects × Year	Yes		Yes		Yes	
R-squared	0.8228		0.5363		0.9350	
Number of clusters	107		106		92	
Number of observations	1474		1234		496	

Notes: Observations are at the city-year level. Dependent variables are any one of the crude death rate, typhoid death rate, and infant mortality rate. Crude death rate is the number of deaths per 1,000 people. Typhoid death rate is the number of deaths from typhoid fever per 1,000 people. Infant mortality rate is the number of infant deaths per 1,000 live births. *Water* is the number of water taps per 100 total population. Demographic controls include the natural logarithm of the total population and shares of population aged 0–14, 15–24, and 25–59 years. Socioeconomic controls include the natural logarithm of total revenue, number of doctors per 100 people, and proportion of factory workers per 100 people. Period dummy is an indicator variable that equals one for periods after 1931. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table G.10: Estimation results for cause-specific death rates: wild cluster bootstrap technique for few clusters issue

Dependent variable	*Water*	R-squared	Number of clusters	Number of observations	Baseline controls × period dummy	City- and Year-fixed effects	City fixed effects × Year
Gastrointestinal infections	-0.079**	0.8319	26	264	Yes	Yes	Yes
	(0.037)						
Typhoid fever	-0.043**	0.6194	26	264	Yes	Yes	Yes
	(0.017)						
Dysentery and diarrhea	-0.036*	0.8684	26	264	Yes	Yes	Yes
	(0.021)						
Respiratory infections	-0.040	0.7347	26	264	Yes	Yes	Yes
	(0.056)						
Measles	0.001	0.4786	26	264	Yes	Yes	Yes
	(0.004)						
Scarlet fever	-0.003**	0.3139	24	257	Yes	Yes	Yes
	(0.001)						
Whooping cough	0.002	0.4279	26	264	Yes	Yes	Yes
	(0.006)						
Diphtheria	-0.003	0.8101	26	264	Yes	Yes	Yes
	(0.002)						
Influenza	0.000	0.6602	26	264	Yes	Yes	Yes
	(0.007)						
Tuberculosis	-0.002	0.9005	26	264	Yes	Yes	Yes
	(0.012)						
Bronchitis	-0.002	0.8576	26	264	Yes	Yes	Yes
	(0.005)						
Pneumonia	-0.033	0.7558	26	264	Yes	Yes	Yes
	(0.032)						

Notes: All cause-specific death rates are defined as the proportion per 1,000 people. Of the sample for scarlet fever, Kawasaki and Moji cities are dropped because of missing values. Gastrointestinal infections include deaths from typhoid fever, dysentery, and diarrhea. Respiratory infections include deaths from measles, scarlet fever, whooping cough, diphtheria, influenza, tuberculosis, bronchitis, and pneumonia. Baseline controls include both demographic and socioeconomic variables. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. The wild bootstrap standard errors with 1,000 replications are in parentheses.

Table G.11: Flexible estimates: impact of modern water-supply system

	Crude death rate		Typhoid death rate		Infant mortality rate	
	(1)	(2)	(3)	(4)	(5)	(6)
Water	-0.109*	-0.108*	-0.009	-0.010*	-0.817	-0.963
	(0.063)	(0.063)	(0.006)	(0.006)	(0.588)	(0.603)
Water× *Consumption*	-0.002	-0.002	0.000	0.000	-0.003	-0.0006
	(0.002)	(0.002)	(0.000)	(0.000)	(0.009)	(0.009)
Baseline controls	Yes		Yes		Yes	
Baseline controls ×period dummy		Yes		Yes		Yes
F-statistic p-value on joint significance of baseline controls	0.0000	0.0000	0.0026	0.0016	0.3746	0.0089
City- and year- fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects × Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.8266	0.8293	0.5241	0.5302	0.8951	0.8962
Number of clusters	108	108	108	108	102	102
Number of observations	1596	1596	1377	1377	648	648

Notes: *Consumption* is the total amount of annual water supply divided by both the total population and 365 days (liters). Baseline controls include both demographic and socioeconomic variables. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table G.12: Flexible estimates: using city size interaction term

	Crude death rate		Typhoid death rate		Infant mortality rate	
	(1)	(2)	(3)	(4)	(5)	(6)
Water	-0.096	-0.081	-0.012	-0.013	-3.279	-3.514
	(0.074)	(0.070)	(0.009)	(0.009)	(2.450)	(2.435)
Water×*Middle city*	0.057	0.030	0.009	0.010	2.995	2.981
	(0.092)	(0.091)	(0.011)	(0.011)	(2.548)	(2.537)
Water×*Large city*	-0.243	-0.264	0.004	0.004	1.814	1.801
	(0.187)	(0.182)	(0.011)	(0.011)	(2.548)	(2.540)
Baseline controls	Yes		Yes		Yes	
Baseline controls ×period dummy		Yes		Yes		Yes
F-statistic p-value on joint significance of baseline controls	0.0000	0.0000	0.0024	0.0023	0.2739	0.0105
City- and year- fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects × Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.8264	0.8289	0.5223	0.5288	0.89655	0.8976
Number of clusters	108	108	108	108	104	104
Number of observations	1639	1639	1416	1416	656	656

Notes: *Middle city* and *Large city* are indicator variables that equal one if city's population is in middle 33% and in top 33%, respectably. Baseline controls include both demographic and socioeconomic variables. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table G.13: Flexible estimates controlling additional factors

	Crude death rate		Typhoid death rate		Infant mortality rate	
	(1)	(2)	(3)	(4)	(5)	(6)
Water	1.207	1.305	0.027	0.011	3.025	0.756
	(1.239)	(1.166)	(0.052)	(0.049)	(7.102)	(8.023)
Water×*Population*	-0.121	-0.130	-0.003	-0.002	-0.325	-0.160
	(0.113)	(0.107)	(0.004)	(0.004)	(0.567)	(0.639)
Baseline controls	Yes		Yes		Yes	
Baseline controls ×period dummy		Yes		Yes		Yes
Additional controls	Yes		Yes		Yes	
Additional controls ×period dummy		Yes		Yes		Yes
F-statistic p-value on joint significance of baseline controls	0.0001	0.0000	0.0059	0.0020	0.3687	0.0000
City- and year- fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects × Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.8307	0.8343	0.5255	0.5414	0.8980	0.9008
Number of clusters	108	108	108	108	104	104
Number of observations	1638	1638	1416	1416	656	656

Notes: Baseline controls include both demographic and socioeconomic variables. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. Cluster-robust standard errors are in parentheses.

Table G.14: Number of bacterial colonies (/ml) in source water and taps

Year	Number of observations	Bacterial colonies (/ml) (a)Source water	(b)Taps	(a)-(b)
1922–1925	11	37.9	27.0	11.0
1926–1928	11	9.3	12.9	-3.6
1929–1931	14	4.7	15.9	-11.2
1932–1934	16	13.3	5.7	7.6
1935–1937	19	5.2	2.8	2.4
1938–1940	8	2.8	2.3	0.4
Overall	79	11.6	10.4	1.2

Note: Cities that recorded the number of bacterial colonies at both sampling points are used from our sample, described in Section 3. The numbers of observations in the sample without filtration technology is 79. Although the paired *t*-test is used to test whether the mean of the number of bacterial colonies is the same in two water-sampling points, the null hypotheses are not rejected in all cases. *Source*: Numbers of bacterial colonies are obtained from the Federation of Water Authorities (1922–1932) and Water Works Association (1934–1943); the timing of installation of filtration technologies is obtained from the Japan Water Works Association (1967b, 1967c, 1967d).

Appendix H Photographs of water-supply systems

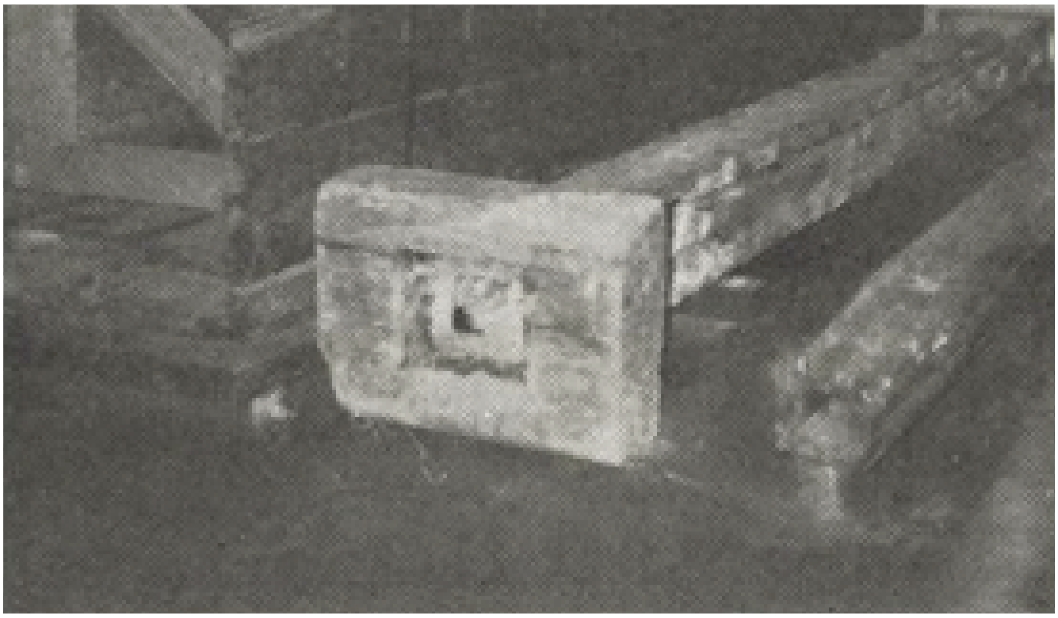


Figure H.1: Wooden pipe of the old water-supply systems (*Mokuhi*)
Note: This photograph shows a part of the old wooden pipe. Source: Water Supply and Environmental Sanitation Department of the Ministry of Health and Welfare (1990).

Figure H.2: Cast-iron pipes of the modern water-supply system (*Chutetsukan*)
Note: This photograph shows cast-iron pipes in the iron pipe-testing station in Toyohashi city.
Source: Toyohashi City Office (1930).

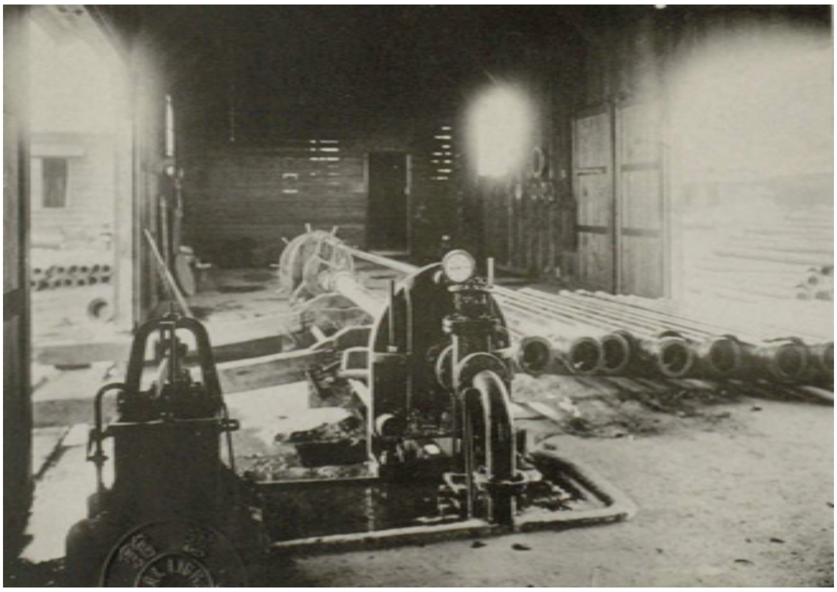


Figure H.3: Cast iron pipe-testing station (*Tekkan shikenjyo*)

Note: This photograph shows the cast iron pipe-testing station in Toyohashi city. Source: Toyohashi City Office (1930).

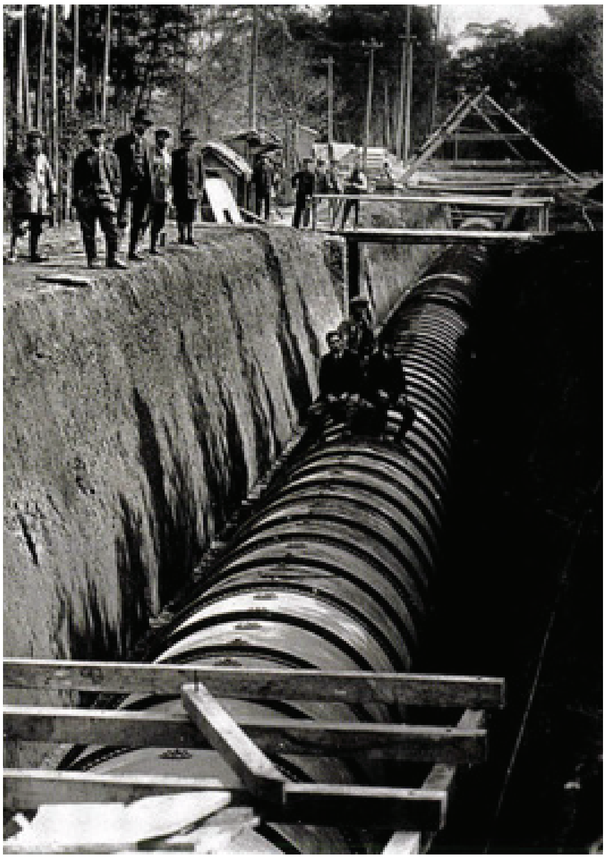


Figure H.4: Cast-iron pipe (*Chutetsukan*)

Note: This photograph shows a cast iron pipe-laying operation at the Sakai and Wadabori line in 1923. Source: Bureau of Waterworks, Tokyo Metropolitan Government (1999a).

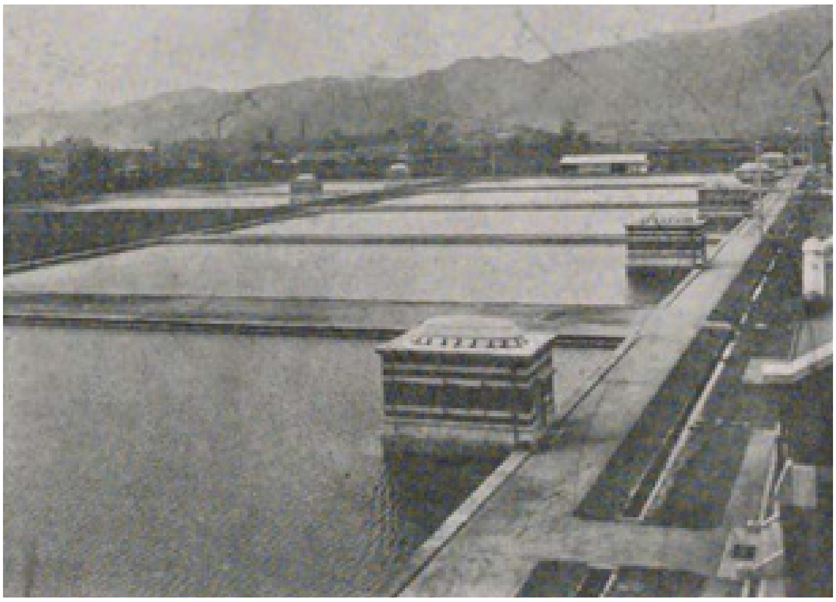


Figure H.5: Slow sand-filtration system in a water-purification plant (*Rokachi*)

Note: This photograph shows the slow sand-filtration system in a water-purification plant in Hiroshima city. Source: Hiroshima City Office (1931).

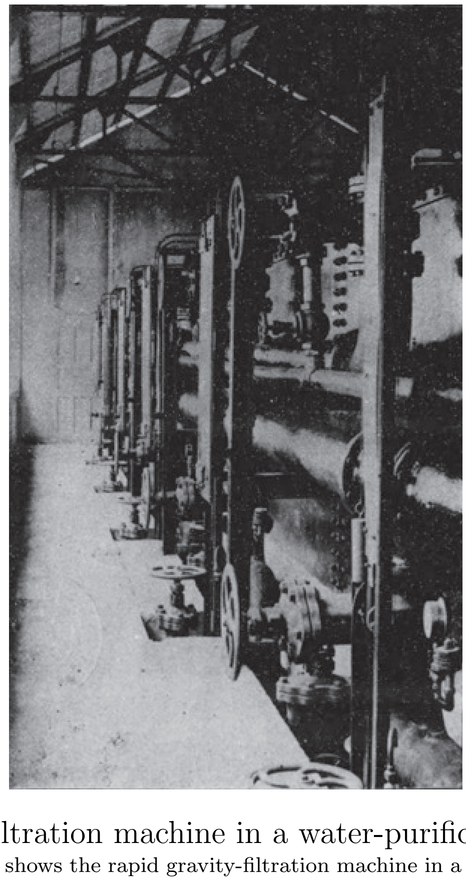


Figure H.6: Rapid-filtration machine in a water-purification plant (*Rokaki*)

Note: This photograph shows the rapid gravity-filtration machine in a water-purification plant in Omuta city. Source: Waterworks Division of Omuta City Office (1924).

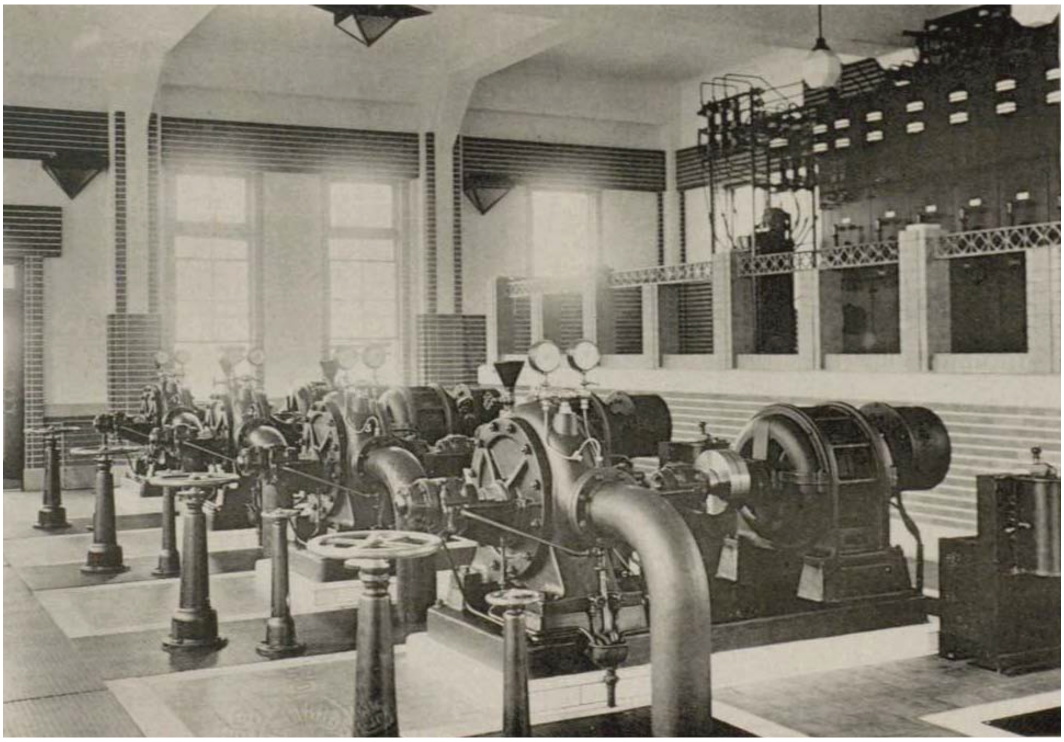


Figure H.7: Pump room in a water-purification plant (*Shokuto*)

Note: This photograph shows the pump room in a water-purification plant of Toyohashi city.
Source: Toyohashi City Office (1930).

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