

## Water systems and urban sanitation: A historical comparison of Tokyo and Singapore

Yurina Otaki, Masahiro Otaki and Osamu Sakura

### ABSTRACT

The importance of a water supply and sewage treatment for urban sanitation is recognized in the modern world. Their contributions to public health have not, however, been well demonstrated by historical data, especially in Asian cities. In this research, we focused on the Asian cities of Tokyo and Singapore, which both developed significantly in the 20th century. We analysed their development processes statistically to determine what the key elements for the protection of urban sanitation have been. Although both cities constructed modern water supply systems at almost same time (Tokyo in 1898 and Singapore in 1878), and similarly modern wastewater treatment systems (Tokyo in 1922 and Singapore in 1913), the prevalence of water-borne diseases in Tokyo was more serious than it was in Singapore, in spite of Singapore's high infant mortality rate. The main reason for this was the differences in the systems of night-soil transport. We found that the water supply system in itself was not enough to resolve all urban sanitation problems, and appropriate night-soil removal was also crucial. In addition, historical trends and water consumption vary by city, so the appropriate technology and system are also different according to the unique characteristics and needs of each.

**Key words** | night-soil, sewage system, urban sanitation, water-borne diseases, water supply

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### INTRODUCTION

The epidemic of cholera in the 19<sup>th</sup> century forced municipalities worldwide to address urban sanitation issues and construct modern water supply systems. For example, in London the introduction of a sand-filtered water supply was encouraged because of the fact that the infection rate of cholera in the area supplied with filtered water was significantly lower than that of other areas. Many world cities adopted filtered water supply systems similar to the one in London. The effectiveness of filtration was subsequently proved in the German cities of Hamburg and Altona. In 1892, the number of cholera patients in Hamburg, where the supplied water was not filtered, was much larger than in Altona, where filtered water was supplied, even though they had the same water source (Safe Drinking Water Committee, National Research Council 1977).

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The importance of appropriate sewage handling, especially night-soil removal from the city, was also recognized as important, and in London the construction of a sewage system began in 1855. Many cities referred to the example of London. However, a water supply usually took precedence over sewage treatment because municipalities could not afford to construct both, and sewage treatment had not been trusted to protect sanitation as efficiently as the water supply systems.

Today, the importance of a water supply and sewage treatment is recognized. However, their contributions have not been proved by historical data, especially in Asian cities. In this research, we focused on Asian cities that developed in the 20th century, and analysed the development processes statistically to show the key elements for protection of urban sanitation.

We selected the Asian cities Tokyo and Singapore in developed countries because both cities had constructed modern water supply systems at almost the same time (Tokyo in 1898 and Singapore in 1878), and the modern wastewater treatment systems similarly (Tokyo in 1922 and Singapore in 1913). Because Singapore was one of the colonies of the United Kingdom, its infrastructure and social systems were influenced by the UK. Additionally, the system in Tokyo modelled the one in use in the UK. By historically comparing these two cities' urban sanitation, we could determine both the common and unique characteristics of each city.

The results of this study should provide good indicators (and a sound basis for selection) regarding possible system effectiveness for cities in developing countries whose water supply and sewage systems are yet to be constructed.

## METHODS

### Historical data collection

To compare the history in Tokyo and Singapore, we collected data related to urban water systems and data for urban sanitation in the period 1880–2000 from statistical documents of each city as follows:

#### Data related to urban water systems

To investigate water use in daily life, we calculated the amount of water supplied by waterworks per capita per day using statistical data from Tokyo and Singapore. In addition, to determine the progress of water-related systems in each city, we collected the coverage ratio of modern waterworks and sewage treatment systems also using statistics from Tokyo and Singapore (Tokyo Metropolitan Government (Bureau of waterworks) 1899–2000, Tokyo Metropolitan Government (Bureau of sewerage) 1945–2000, Annual statistics of waterworks in Japan 1954–1999, Yearbook of Statistics Singapore 1967–2001).

#### Data for urban sanitation

To evaluate urban sanitation, the infant mortality rate was used as a general indicator, and the infection rates of

water-borne diseases such as cholera, enteric fever and dysentery were also used as indicators influenced by water system conditions. Because both cities suffered from these diseases, we could collect the data using statistical books (Tokyo statistical yearbooks 1881–2000, Administrative reports of the Singapore municipality 1896–1936, Annual reports of Ministry of Health Singapore 1949–1960, Communicable diseases surveillance in Singapore 1991–2001, Yearbook of Statistics Singapore 1967–2001). As infection by such diseases originated not only in the water, but in food as well, pinpointing the origin for every case was impossible. A continuous epidemic of these diseases is generally regarded as being water related (*The Merck Manual* 1999).

### Comparison of Tokyo and Singapore

We selected Tokyo and Singapore for the case study, because construction of the water-related infrastructures was begun at almost the same time, and both were markedly developed after the Second World War. In contrast, their climates are different; Singapore is tropical and Tokyo is temperate, and therefore we could also compare the effects of climate.

By comparing the historical data of Tokyo and Singapore statistically, we could find what was common and what was different between the cities.

## RESULTS AND DISCUSSION

### Historical survey in Tokyo

Before the construction of modern waterworks in Tokyo, water was supplied by aqueducts, deep wells and water vendors. There were, however, many lowland areas near seashores where deep wells could not be used for drinking because of the salt. Water, which flowed down through aqueducts, was stored in the wells ('stored wells'), which had a bottom. There were no water treatment technologies such as disinfection or filtration. With the population increase, the well water was eventually polluted and the cholera epidemic became a major problem. Therefore, the municipality decided to construct a modern waterworks (Horikoshi 1995).

The water supply system, which would use a modern waterworks infrastructure, was begun in 1898, with the first phase of construction completed in 1911 (Tokyo Metropolitan Government 1999). At the beginning of the 20th century, the total amount of consumed water from the supply was about 100 l per day per capita, which was one-quarter of today's level. It stopped rising prior to the Second World War, whereas its increase again after the 1950s, along with the city's high-growth rate, was remarkable. In 1972, it achieved a maximum consumption of 532 l per day per person, and then decreased to around 400 l per day per person (Figure 1). During and just after the Second World War, the data were not credible because of the war disturbances.

We could ascertain the amount of water for domestic (household) use only after 1972. In the 1970s, the percentage of domestic water was about 50–60% of the total water use. Its percentage increased gradually, and now it is almost 70% of the total water used. This may be because of deliberate water saving in the industrial and commercial sectors. If we assumed that 50–60 l per day per capita was also used for domestic purposes at the beginning of the 20th century, then this was sufficient for a sanitary quality of life.

The percentage of people who could use treated water reached 77.3% in 1909. Because Tokyo municipality's

efforts to increase its capacity could not catch up with the population growth and because infrastructure was destroyed during wartime, the percentage did not reach near 100% until the 1970s.

Construction of the modern wastewater collection and treatment systems was significantly behind that of the water supply systems. Although it started in 1922, the percentage of people who could actually use it was only 10% after the Second World War. After that, construction proceeded very rapidly and in earnest, and finally covered all of Tokyo city by 1994.

At the beginning of the 20th century, sanitary conditions in Tokyo city were bad, and there was a high infant mortality rate (192 per 1,000). Cholera was brought under control at the end of 19th century, when the construction of water supply systems began (Figure 2). The worldwide level of cholera was also stable until the next epidemic began in the 1960s. Therefore, in Tokyo's case, it is clear that the infection rate of cholera is not an adequate indicator for evaluating improvements to public sanitation resulting from the water supply systems.

On the other hand, the infection rate of enteric fever was constant at around 0.1–0.2% from 1880 to 1940, and its prevalence was brought under control after the Second World War. In order to distinguish the relationship between

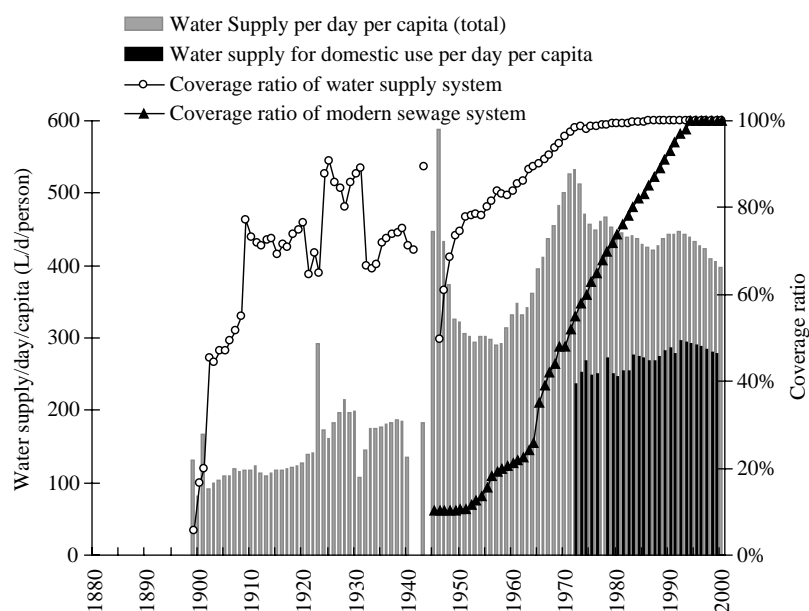
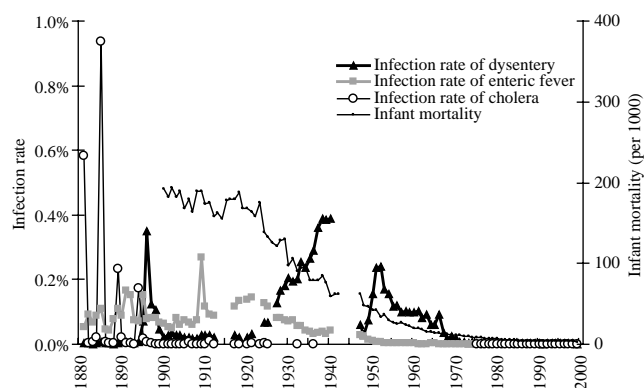


Figure 1 | Historical statistics of water supply and sewage system in Tokyo (amount of water supply and coverage ratio).



**Figure 2** | Historical statistics of indicators for urban sanitation in Tokyo (Infant mortality and infection rate of water-borne diseases).

water systems and prevalence of enteric fever, we could divide Tokyo history into five periods as follows:

1st stage (1881–1898): No treated water supply. No modern sewage treatment.

2nd stage (1899–1909): Percentage of treated water supply <70%. No modern sewage treatment.

The percentage of people who can use treated water increased year by year.

3rd stage (1910–1940): Percentage of treated water supply >70%. No modern sewage treatment.

The percentage of people who can use treated water stopped increasing.

4th stage (1946–1968): Percentage of treated water supply >70%. Percentage of modern sewage treatment <40%.

5th stage (1969–): Percentage of treated water supply >70%. Percentage of modern sewage treatment >40%.

The average enteric fever infection rate was 0.090% in the 1st stage, 0.084% in the 2nd stage, and 0.080% in the

3rd stage. Results of the Aspin-Welch-test (level of significance <0.01) do not show a significant difference between the infection rates across these three historical stages. Therefore, it is clear that the introduction of treated water supply systems was insufficient to contain the spread of water-borne diseases.

In the case of dysentery, although more than 70% of the people could use treated water, the infection rate increased during the 3rd stage. During the 4th stage, it began to decrease along with the construction of modern sewage treatment systems. The correlation coefficient between infection rate and the number of people who could use the modern sewage treatment system is -0.706 ( $p < 0.05$ ). Therefore, there is a significant relation between them.

In addition, we have to investigate the infectious diseases that originated from foreign countries and were not related to the daily life of the city. Since there was not enough city-based data, we investigated country-based cases. In Japan, the increase in the comings and goings of travellers resulted in the import of infectious diseases after the 1970s. In 1988, 30–40% of the enteric fever cases and 50–60% of the cases of dysentery were from foreign countries (Table 1) (Matsushita 2000). Because the number of travellers before 1970 was less than a quarter of that today (in Tokyo, 733,194 in 1962 and 3,063,433 in 2000), most of the water-related diseases before the 1970s originated in local circumstances.

### Historical survey in Singapore

Before the construction of a modern waterworks, the people in Singapore used wells. They faced the same problems as Tokyo did with their own expanding popu-

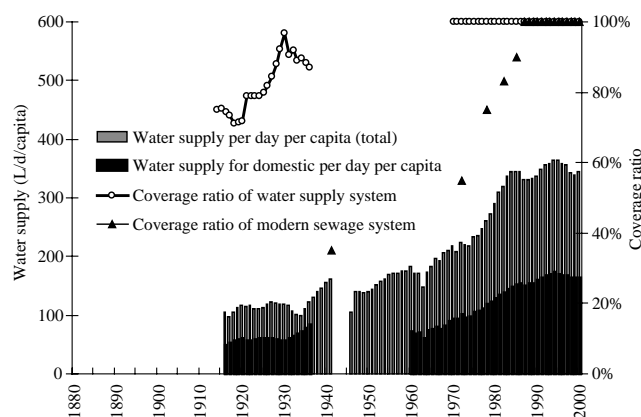
**Table 1** | Imported infectious diseases in Japan (1988–1997)

		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Enteric fever	Total	111	105	120	106	71	129	71	64	81	79
	% of imported	36%	47%	46%	45%	44%	35%	62%	66%	65%	63%
Dysentery	Total	947	826	808	1000	993	968	892	902	1063	1112
	% of imported	58%	67%	71%	52%	57%	57%	72%	78%	68%	81%

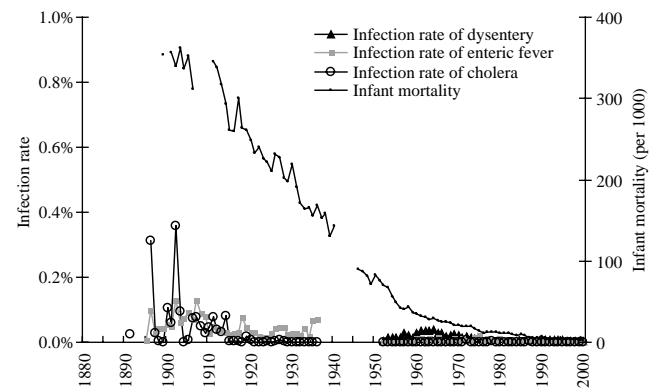
lation. Construction of a water supply using modern waterworks was begun in 1878 (Jayakumar 1989; Yeoh 1996). At the beginning of the 20th century the total amount of water supplied was about 106 l per day per capita, almost the same as in Tokyo; half of that was for domestic use. The amount of water supplied increased slowly before independence from the United Kingdom in 1965. After that it increased at a higher rate and achieved a maximum consumption rate of 359 l per day per capita in 1993 (Figure 3). About 40–50% of the total water supply was for domestic water use. If we assumed that 50–60% of the total water supply was used for domestic purposes at the beginning of the 19th century, then 40–50 l per day per capita was enough for a sanitary quality of life. This amount was almost the same as in Tokyo.

The proportion of people who could use treated water had already reached 78% in 1916, and 100% in 1970; there is, however, no data about the situation between 1937 and 1969. The construction of the modern sewage system began in 1913, and made rapid progress from the 1930s to the 1950s (Leng 2000). The coverage ratio reached 35% in 1941 and 100% in 1987. This was slightly faster than in Tokyo.

At the beginning of the 20th century, the sanitary conditions in Singapore were also bad, with even higher infant mortality rates (354 per 1,000) than in Tokyo. However, the infection rate of enteric fever was lower, below 0.1%, and an epidemic of dysentery was of so little consequence that no data exists for its infection rate (Figure 4). There were outbreaks of cholera, but its infection



**Figure 3** | Historical statistics of water supply and sewage system in Singapore (amount of water supply and coverage ratio).



**Figure 4** | Historical statistics of indicators for urban sanitation in Singapore (Infant mortality and infection rate of water-borne diseases).

rate was much lower than in Tokyo. As a result, water-borne diseases were not so serious a problem in Singapore, although the infant mortality rate was much higher than that of Tokyo.

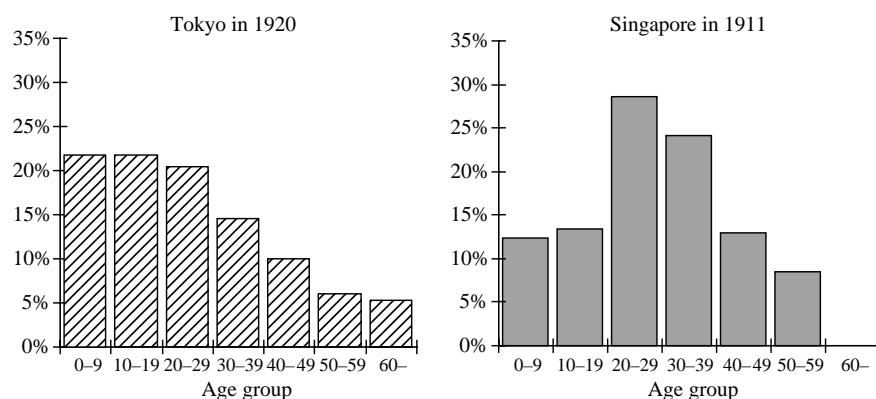
### Comparison of Tokyo and Singapore

Why, in spite of the high infant mortality rate in both cities, was the prevalence of water-borne diseases in Tokyo more serious than in Singapore? We consider several possibilities to answer this question.

The first possible reason was the system of night-soil transport. Night-soil is a source of pathogens and should be carefully removed from living areas. In both cities, night-soil was accumulated in cesspools, collected manually, and moved to suburbs to use as fertilizer after fermentation. However, there was a significant difference between these cities in their night-soil handling and transportation methods.

In the case of Singapore, the municipality adopted 'the two-pail system' for night-soil collection (Singh 1989; Middleton 1900; Yeoh 1996). This was a very simple method for collecting night-soil: the clean pail replaced the filled pail on the spot and night-soil vans would then transport the pails to a cleaning depot. This simple method prevented any physical contact with the night-soil, which was a source of pathogens.

In the case of Tokyo, there was no such system, and night-soil was scooped up by a ladle (before the introduction of vacuum cars after the Second World War). When scooping up night-soil from cesspools, it would invariably spill and



**Figure 5** | Comparison of age structure in Tokyo and Singapore in early 19th century.

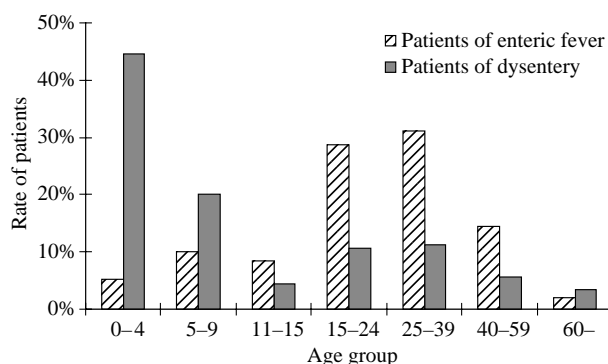
contaminate the ground. This increased the risk of human exposure to pathogens. Additionally, the construction of modern sewage treatment facilities in Singapore was faster than in Tokyo, and the coverage rate of modern sewage treatment in Singapore reached about 40% in 1940. This 40% rate might be a standard for maintaining urban sanitation, because water-borne diseases in Tokyo disappeared in the 1970s, when the coverage rate reached 40%. As a result, it is clear that appropriate night-soil removal, whether it is under or over ground, is key for proper urban sanitation.

The second possible reason for Singapore's lower disease prevalence is the difference in the age structure of the city, especially concerning the prevalence of dysentery. Singapore was a British colony until 1965. Large numbers of men (mainly from China, India and Malay) came as migrant workers and went back to their home countries after earning money. This caused a distorted age structure (Figure 5) (Tokyo statistical yearbook 1920; Singapore Municipality records 1911). Large numbers of people belonged to the age groups 20–29 and 30–39, and the number of women and children was relatively small. This trend continued until the 1930s. We analysed the number of patients with enteric fever and dysentery in Tokyo in 1940 when the dysentery epidemic was severe (Figure 6) (Tokyo statistical yearbook 1940). This indicated that dysentery was a big problem for the younger generation because 70% of the patients with dysentery in 1940 were under 15. The lack of any significant prevalence of dysentery in Singapore at the beginning of the 20th century could be explained at least partly by this.

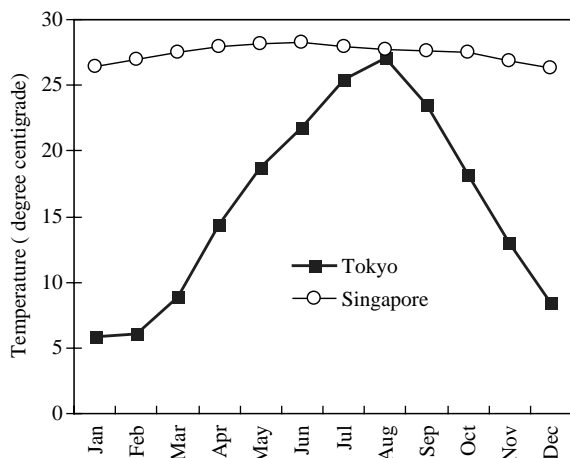
Third, there is a possibility that the difference in climate influenced the prevalence of water-borne diseases.

The night-soil was used as fertilizer after it fermented in a receptacle to kill pathogenic bacteria. If it was not fully fermented, the vegetables that were grown with it had a significant risk of being contaminated. The higher the temperature, the more the fermentation process is accelerated. The temperature in Singapore is always higher than 25°, but that in Tokyo varies throughout the year and goes down to below 10° for four months (Figure 7) (National Astronomical Observatory 2000). Therefore, the climate in Singapore is more suitable for the fermentation process.

What we can learn from this survey is that well-integrated water systems can avoid over-investment. Today, to assure sanitary conditions in developing countries, there have been many projects to construct water supply systems in the cities of such countries. However, this is inefficient and will result in over-investment. In Tokyo in 1970 when infection by water-borne diseases was eradicated, the coverage rate of waterworks



**Figure 6** | Patients with enteric fever and dysentery by age group in Tokyo in 1941.



**Figure 7** | Average temperature by month in Tokyo and Singapore (average of 30 years).

was about 94%, that of the sewage system was about 50%, and water consumption for domestic use was about 240 l per person per day, 85% of today's level. In Singapore in 1920 when there was a low incidence of water-borne diseases, the coverage rate of waterworks was about 80%, the two-pail system was used for night-soil collection, and water consumption for domestic use was about 60 l per person per day, one-third of today's level of consumption. To supply too much water is not a good solution.

## CONCLUSION

From a historical review and comparison of Tokyo and Singapore, we suggest that water supply systems are not sufficient to solve the problems of urban sanitation, and effective night-soil removal is one of the key related elements. In addition, as historical trends in the amount of water use differ by city, the suitable technologies are also different according to city characteristics, and the construction of a well-integrated water system is imperative.

Today, to assure sanitary conditions in developing countries, there have been many projects to construct water supply systems in their respective cities. However, it is not always the best choice to duplicate the water systems in another city. We should take into account the city's unique character and carefully consider what the most suitable system is for each individual case.

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