Water systems and urban sanitation in Tokyo and Singapore during the 19th to 20th centuries

Yurina Otaki

University of Tokyo, Interdisciplinary Information Studies

Address: 7-3-1 Hongo, Bunkyo, Tokyo 133-0033, Japan

phone: +81 3 5841 2662

fax: +81 3 5841 2662

e-mail: yurina@iii.u-tokyo.ac.jp

Abstract

The epidemic of cholera in the 19th century forced municipalities to address urban sanitation and construct modern water supply systems, which delivered treated (filtered and disinfected) water to the inhabitants. The importance of removing sewage, especially excrement, from the city was also recognized as significant. However, the water supply usually took precedence over sewage treatment because municipalities could not afford to construct both systems, and sewage treatment was not trusted to provide sanitation as efficiently as water supply systems.

Nowadays, the importance of water supply and sewage treatment is recognized. However, its contribution has not been proven by historical data, especially in Asian cities. In this research, we focused on Asian cities (Tokyo and Singapore) which developed sewage treatment facilities in the 20th century, and analyzed the development process statistically to show what the key elements for protection of urban sanitation are.

By comparing these two cities' urban sanitation historically, we could suggest that water supply systems were not enough to solve the problems of urban sanitation, and effective excrement removal was one of the key elements related to it. In addition, the suitable technologies are different according to city characteristics, and construction of a well-integrated water system is necessary.

The results of this study are intended to be good advance indicators for the cities in developing countries whose water supply and sewage systems will be constructed in the future.

Introduction

The epidemic of cholera in the 19th century forced municipalities to address urban sanitation 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 ratio of cholera in the area supplied with filtered water was significantly lower than in other areas. Many cities in the world adopted filtered water supplies similar to the London type. The effect of filtration was proved in the German cities of Hamburg and Altona in 1892; the number of patients with cholera in Hamburg, where the supplied water was not filtered, was much larger than those in Altona, where filtered water was supplied, even though they had the same water source.

The importance of removing sewage, especially excrement, from cities 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, water supply treatment facilities usually took precedence over sewage treatment because municipalities could not afford to construct, and sewage treatment was not trusted to provide sanitation as efficiently as water supply systems.

Nowadays, the importance of water supply and sewage treatment is recognized. However, its contribution has not been proven by historical data, especially in Asian cities. In this research, we focused on Asian cities which developed in 20th century, and analyzed the development process statistically to show what the key elements for protection of urban sanitation are.

We selected two cities in developed Asian countries, Tokyo and Singapore (Fig. 1), because both cities had constructed modern water supply systems at almost the same time (Tokyo in 1898, and Singapore in 1878), and also the modern waste water 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 system were influenced by the UK, and the system in Tokyo also modelled the one in use in UK. Their climates are markedly different -- that of Singapore is tropical and that of Tokyo is moderate -- and therefore we could compare the effect of climate. By comparing these two cities' urban sanitation historically, we could find the elements common between these cities and those characteristics of each city.

The results of this study are intended to be good indications for those cities in developing countries whose water supply and sewage systems will be constructed in the future.

Figure 1: Location of Tokyo and Singapore.

Tokyo water system before the construction of modern waterworks

In Tokyo, which was called Edo before the 19th century, the Edo water system (EWS) had been used before the construction of modern waterworks in 1898. The EWS was used during the 17th to 19th centuries in Tokyo. As there was not enough water in Tokyo, water was supplied in three ways: the Tamagawa and Kanda aqueducts, deep wells, and water vendors. In Tokyo, there were many lowlands and reclaimed land areas near the seashore where most of deep wells could not be used for drinking because of salt. To supply water to such areas, the aqueducts were constructed. The water was taken from rivers or ponds and run down a long distance only by the incline, then stored in a well as a terminal. As stored wells had a bottom, impurities settled out of the water. There was no water treatment technology such as filtration or disinfection. By the end of 19th century, cholera epidemics became a very big problem and the contamination of water by excrement was regarded as contributory.

During this period, excrement was stored in the toilet and brought to suburban fields as an excellent fertilizer. That is to say, excrement was separated from the water system. In spite of this unique excrement collection system, why was the water contaminated? There were some possibilities, as follows:

- Open channels: Because aqueducts ran through open channels for a long distance before reaching the central area, they were defiled with refuse
- Wooden pipes: In the central area, aqueduct ran underground through wooden pipes, which could easily decay
- Well contamination: The close proximity of wells and toilets could cause a higher risk for pollution of the wells by underground or surface means

In 1877 and 1884, the water quality of the Tamagawa and Kanda aqueducts was tested (Atkinson 1878, Municipality of Tokyo 1923). Both tests inspected nitrogen-related substances (NH4+-N, NO2-- N, NO3-- N, etc.), which indicate contamination by excrement. A bacteriological check was not done in either test. In 1877, the water quality in the storage wells was measured i), and in 1884, the water quality in the aqueduct was measured ii). Fig. 2 plots the sampling points of these two quality tests, and Fig. 3 is the result of the quality tests. From these figures, we found that water was polluted when it was stored in the wells, not flowing down into the aqueduct.

The EWS worked well until the 19th century, when cholera prevailed and the sanitary conditions became serious. The epidemic became the driving force to change the EWS to a modernized one.

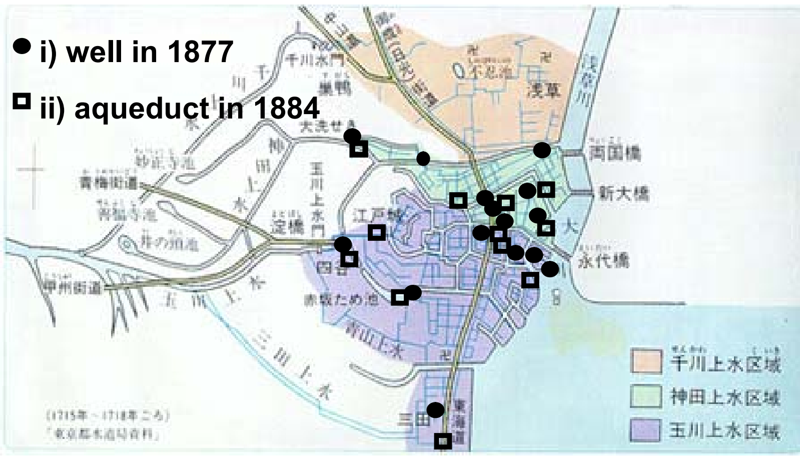


Figure 2: Samping points of water quality test. Map from Mitaka education center.

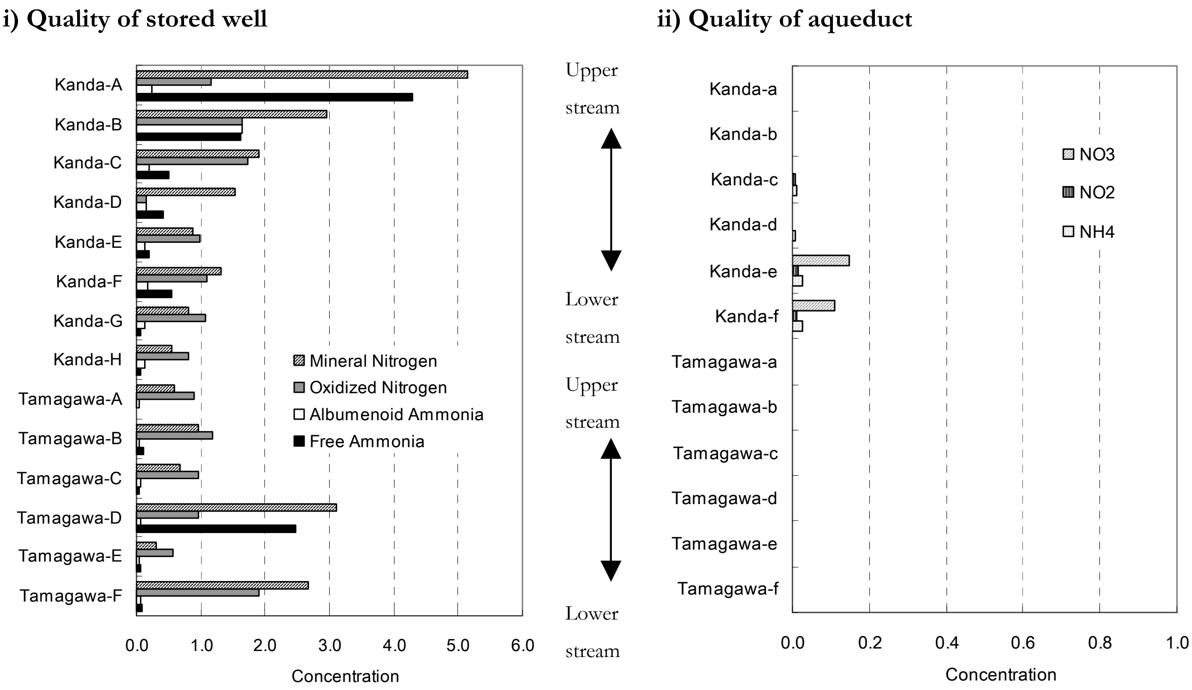


Figure 3: Result of water quality test.

Modern waterworks and urban sanitation in Tokyo

In 1898, modern waterworks began to supply treated water to Tokyo. Many textbooks state that modern waterworks improved urban sanitation. However, it is uncertain that change of supplied water could really improve urban sanitation because, in case of EWS, the problem was not the quality of supplied water but its pollution by users. Actually, the prevalence of cholera was brought under control at the end of the 19th century, when the construction of water supply systems began. But at the same time the worldwide level of cholera was also stable until the next epidemic began in the 1960s. Therefore, we cannot say urban sanitation in Tokyo was improved by control of the prevalence of cholera.

To evaluate urban sanitation, infant mortality rate was considered suitable as a general indicator, and the infection ratio of water-borne diseases other than cholera, such as enteric fever and dysentery, was also suitable as an indicator especially influenced by the water system (Fig. 4). In addition, to know the progress of the water system in each city, we collected the coverage ratio of modern waterworks and the sewage treatment system (Fig. 5). In Tokyo, separate collection of excrement gradually decreased according to the construction of the sewage system.

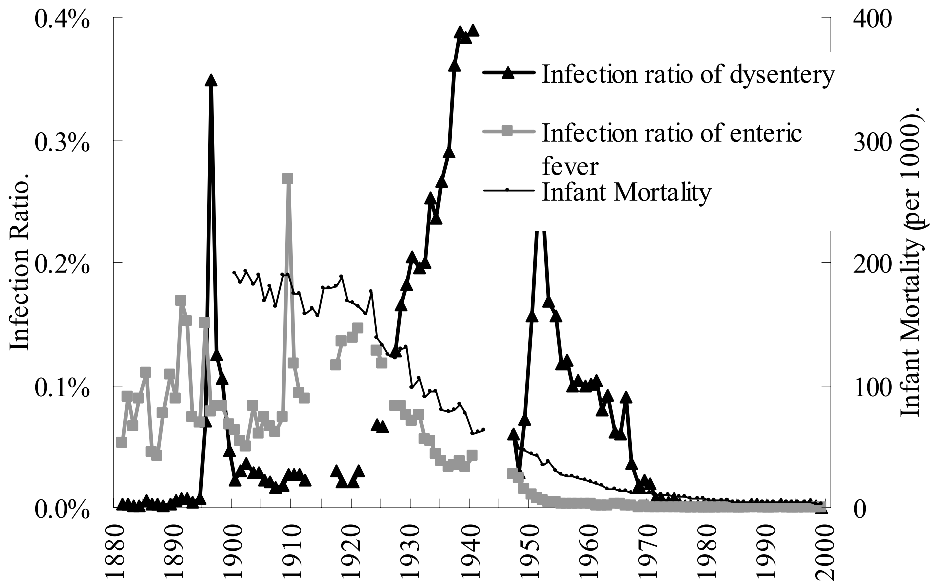


Figure 4: Indicator for urban sanitation in Tokyo. Source: Tokyo statistical yearbook.

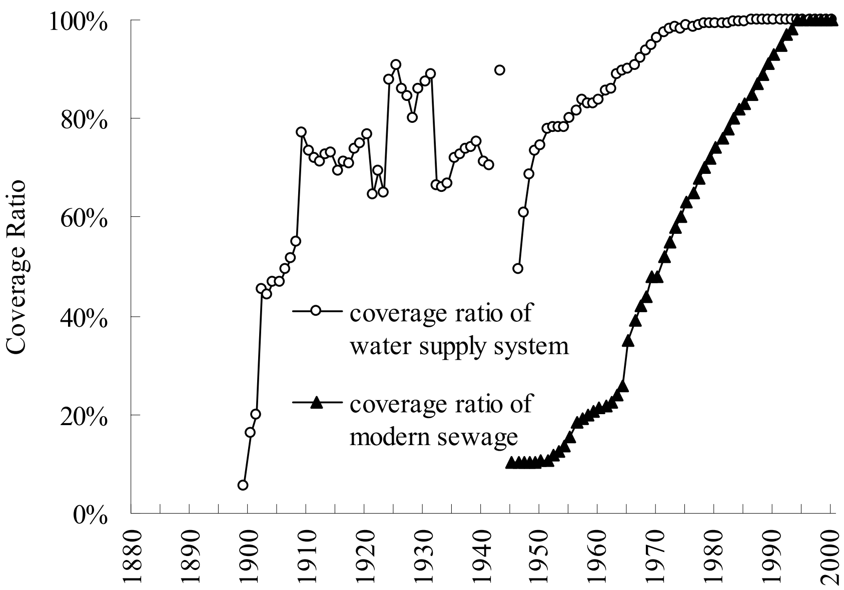


Figure 5: Coverage ratio of modern water supply and sewage system in Tokyo. Source: Bureau of waterworks and sewerage, Tokyo Metropolitan Government.

In the beginning of the 20th century, the sanitary conditions in Tokyo City were bad, with a high infant mortality rate (192 per 1,000). The infection ratio of enteric fever was constant around 0.1-0.2% from 1880 to 1940, and its prevalence was brought under control after WWII. In order to distinguish the relationship between water systems and enteric fever's prevalence, we can divide Tokyo's history into five periods as follows:

	Coverage ratio of modern waterworks	**Coverage ratio of modern sewage treatment**
1st stage (1881-1898)	No	No
2nd stage (1899-1909)	<70% (Increasing year by year)	No
3rd stage (1910-1940)	>70% (Stop increasing)	No
4th sage (1946-1968)	>70%	<40%
5th stage (1969-)	>70%	>40%

The average of enteric fever infection ratio was 0.090% in the first stage, 0.084% in the second stage, and 0.080% in the third stage. As a result of an Aspin-Welch-test (level of significance < 0.01), there is not a significant difference among the infection rates across these three historical stages. Therefore, it was clear that the introduction of treated water supply systems was insufficient to solve all water-borne diseases.

In the case of dysentery, the infection rate increased in the third stage, although above 70% of people had access to treated water. In the fourth stage, dysentery began to decrease in tandem with the construction of modern sewage treatment systems. The correlation coefficient between infection ratio and coverage ratio of modern sewage treatment is -0.706 ($p < 0.05$). Therefore, there is a significant relation between them.

As we expected, only changing the supplied water could not improve urban sanitation by itself. Effective treatment of excrement is also necessary. However, in Tokyo excrement was separated from the water system. Why and how was the contamination occurring? Was there any problem inherent in the collection of excrement?

Modern waterworks and urban sanitation in Singapore

To investigate why and how contamination occurred, we studied the case of Singapore and compared it to the Tokyo case.

Before the construction of modern waterworks, people in Singapore used well water. Excrement was also collected separately and used as a fertilizer. As the same problem as in Tokyo was occurring, a water supply system using modern waterworks began in 1878 (Yeoh, 1996). People who had access to treated water had already reached 78% in 1916, and 100% in 1970, although there are no data about the situation from 1937 to 1969 (Fig. 6). 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 Tokyo.

In the beginning of the 20th century, sanitary conditions in Singapore were also bad, with higher infant mortality rate (354 per 1,000) than that in Tokyo. However the infection ratio of enteric fever was lower, below 0.1%, and an epidemic of dysentery was so minor that no data exist for its infection ratio (Fig. 7). As a result, water-borne diseases were not so serious a problem, although the infant mortality rate was much higher than that in Tokyo.

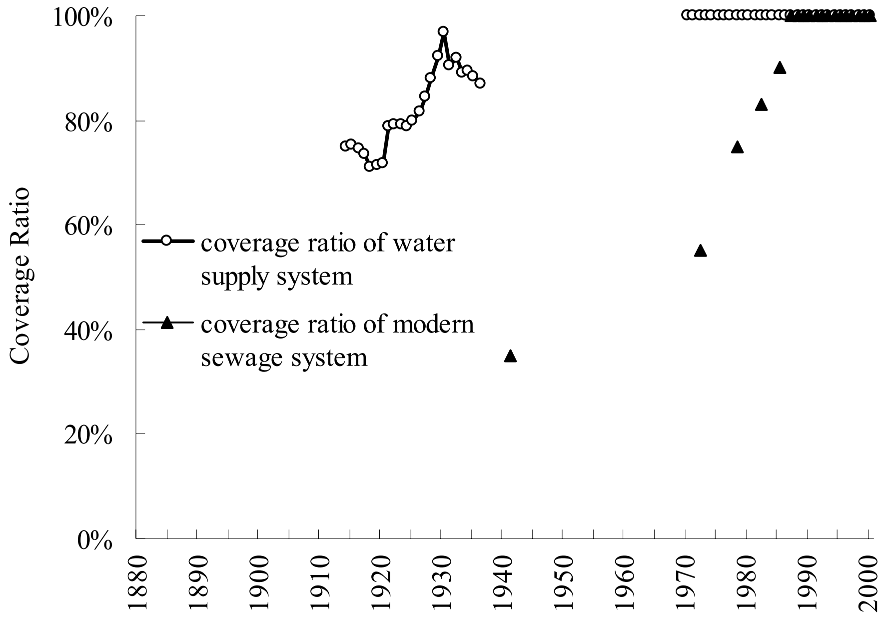


Figure 6: Coverage ratio of modern water supply and sewage system in Singapore. Source: Singapore Municipality Records, Yearbook of statistics.

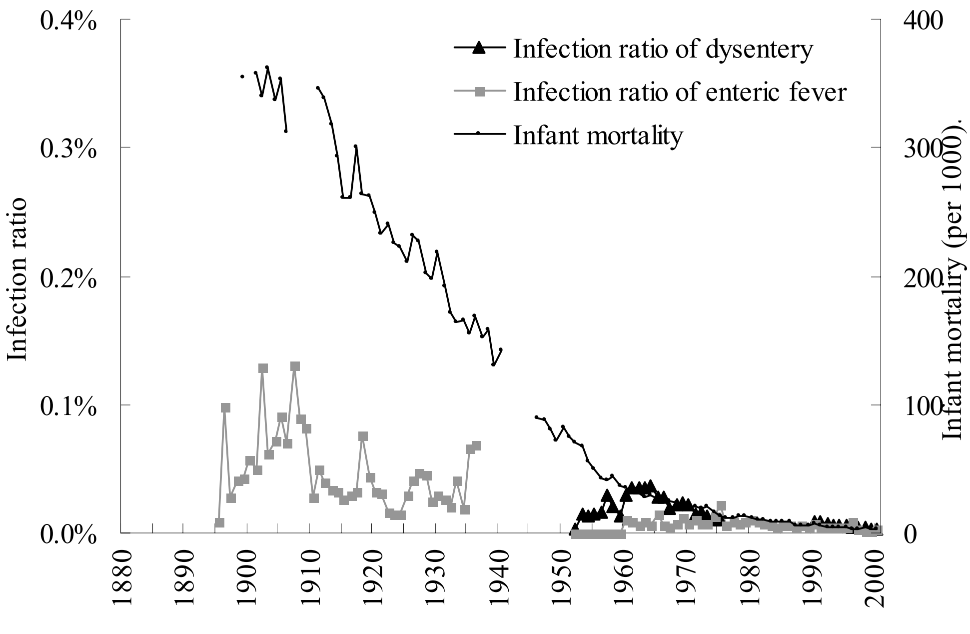


Figure 7: Indicator for urban sanitation in Singapore. Source: Singapore Municipality Records, Yearbook of statistics.

Comparison of Tokyo and Singapore

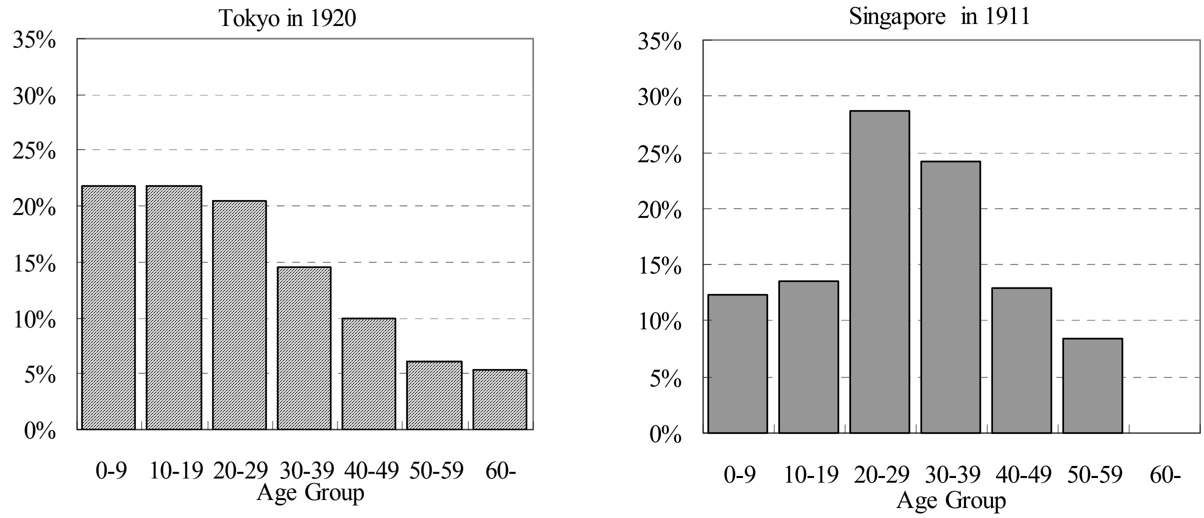
Why was the prevalence of water-borne diseases in Tokyo more serious than that in Singapore in spite of comparable high infant mortality rates in both cities? We considered several possibilities to answer this question.

The first possible reason was due to the system of excrement transport. Excrement is a source of pathogens and should be removed from living areas carefully. In both cities, excrement was accumulated in cesspools, collected manually, and moved to the suburbs in order to be used as fertilizer after fermentation. However, there was a significant difference between these cities in excrement transportation on the ground. In the case of Singapore, its municipality adopted the "two-pail system" for excrement collection (Yeoh, 1996). It was a very simple way to collect the excrement, where the clean pail was replaced with the filled pail on the spot and excrement vans would then transport the pails to a cleaning depot. This simple method prevented people from touching the excrement, a pathogen source. In the case of Tokyo, there was no such system, and excrement was scooped up by a ladle, before the introduction of vacuum cars after WWII. When excrement was scooped up from cesspools, it would spill and contaminate the ground. This increased the risk of people being exposed to pathogens.

In addition, the construction of modern sewage treatment in Singapore was faster than that in Tokyo, and the coverage ratio of modern sewage treatment in Singapore reached about 40% in 1940. This rate, 40%, might be a standard to keep in urban sanitation, because water-borne diseases in Tokyo disappeared in 1970s, when the coverage ratio reached 40%. As a result, it was clear that appropriate excrement removal, whether it underground or over ground, is the key for proper urban sanitation, rather than treated water supply.

The second possible reason for Singapore's lower disease prevalence is the difference in age structure of the city, especially concerning the prevalence of dysentery. Singapore had been one of the British colonies until 1965, and a lot of men arrived there as migrant workers mainly from China, India, and Malaysia, and returned to their home countries after earning money. This caused a distorted age structure (Fig. 8). Large numbers of people belonged to the age groups 20-29 and 30-39, and the numbers of women and children were relatively small. This trend continued until the 1930s.

We analyzed the number of patients with enteric fever and dysentery in Tokyo in 1940 when the epidemic of dysentery was very high (Fig. 9). It 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 in the beginning of the 20th century could be partly explained by this.



(Source: Tokyo statistical yearbook) (Source: Singapore Municipality Records)

Figure 8: Comparison of age structure in Tokyo and Singapore in early 19th century.

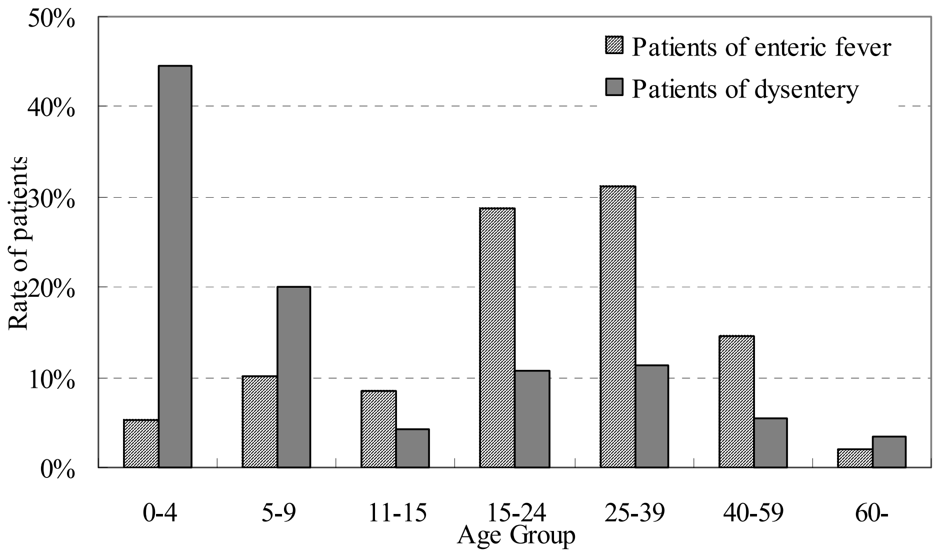


Figure 9: Patients with enteric fever and dysentery by age group in Tokyo in 1941. Source: Tokyo statistical yearbook.

Thirdly, there was a possibility that the difference in climate influenced the prevalence of water-borne diseases. Excrement was used as fertilizer after it fermented in a receptacle to kill pathogenic microorganisms. If it was not fully fermented, the vegetables which grew with it had a risk of contamination. The higher the temperature, the more the fermentation process is accelerated. The temperature in Singapore is always higher than 25o C., and that in Tokyo varies throughout the year and goes down under 10o during a period of four months per year (Fig. 10). Therefore the climate in Singapore is more suitable for the fermentation process.

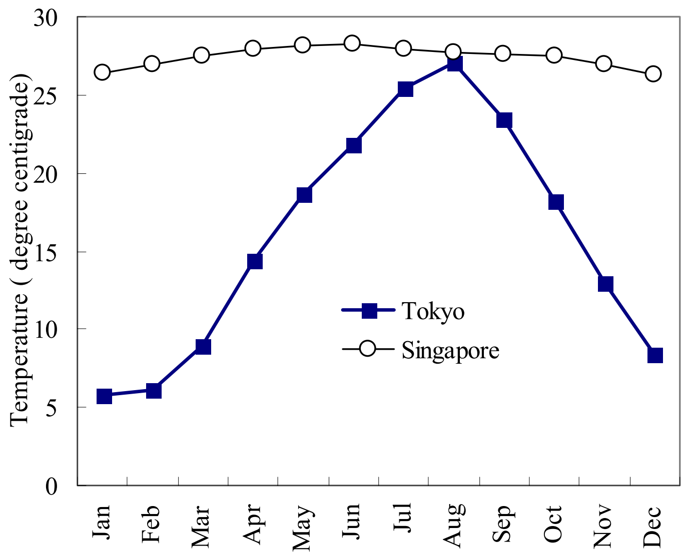


Figure 10: Average temperature by month in Tokyo and Singapore (average of 30 years). Source: Chronological Scientific.

Additionally, what we could learn from this survey was that a well-integrated water system can avoid over-investment. Today, to assure sanitation in developing countries, there have been many projects to construct water supply systems in the cities of such countries. However, this is an inefficient way and will cause over-investment. In Tokyo in 1970, when the infection rate of water-borne diseases was resolved, the coverage ratio of waterworks was about 94%, that of the sewage system was about 50%. In Singapore in 1920, when there was little problem with water-borne diseases, the coverage ratio of waterworks was about 80%, and the two-pail system was used for excrement collection. To construct a complete modern water system is not the only way to improve urban sanitation. A combination of effective technology can realize good urban sanitation.

Conclusion

From a historical review and comparison of Tokyo and Singapore, we could suggest that water supply systems were not enough to solve problems of urban sanitation, and accurate excrement removal was one of the key elements related to it. In addition, suitable technologies are different according to city characteristics, and construction of a well-integrated water system is necessary.

Today, to assure sanitation in developing countries, there have been many projects to construct water supply systems in the cities. However, it is not always the best way to imitate the water system in another city. We should take into account the city's character and think carefully about what the most suitable system is for each case.

Notes

Acknowledgement: This study was supported by CREST (Core Research for Evolutional Science and Technology) of the Japan Science and Technology Corporation. We thank Mr. NG Hang Tong, Public Utility Board in Singapore, who provided essential information about Singapore's water system, and Dr. Keisuke Hanaki, professor of urban engineering in University of Tokyo.

References

Administrative reports of the Singapore Municipality 1896-1936.

Atkinson, R.W. 1878. Water Supply of Tokio, Transaction of the Asiatic Society of Japan 6, pp.87-98.

Bureau of sewerage, Tokyo Metropolitan Government 1945-2000 (in Japanese).

Bureau of waterworks, Tokyo Metropolitan Government 1899-2000 (in Japanese).

Leng, S.B. 2000. Sewers and sanitation in Singapore 1930s-1950s, Academic exercise – National University of Singapore.

Municipality of Tokyo 1923. History of Tokyo – Water Supply (2), pp.923-932 (in Japanese).

National Astronomical Observatory of Japan, Chronological Scientific CD-ROM 2000.

Report on and Estimates for the Disposal of Night Soil 1890.

Report on and Estimates of the Disposal of Night Soil at Singapore 1893.

Singapore Municipality Records.

Tokyo statistical yearbook 1881-2000 (in Japanese).

Website of Mitaka education center.

Yearbook of Statistics, Singapore, 1967-2001.

Yeoh, B.S.A. 1996. Contesting Space: Power Relations and the Urban-Built Environment in Colonial Singapore, Oxford Express.