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Influence of water-related appliances on projected domestic water use in Tokyo

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Abstract:

In this study, the amount of domestic water use was quantified by estimating the usage rates of various water-related appliances. Tokyo Metropolis was selected as a case study because it was relatively easy to obtain detailed data from Tokyo Waterworks Bureau. In the analysis, the calculations for domestic water use reproduced actual usage figures from 1998 to 2006. From the maximum domestic water use per capita in 1997 the projected reduction was estimated to be 9% by 2025 and 10% by 2050. In addition, our results indicate that water use for both bath and toilet is expected to remain high in the future. We performed a simulation assuming that a 6 L-type toilet is installed by all consumers, with the results suggesting that domestic water use per capita per day could reduce to around 200 L. It was therefore concluded that the replacement of a conventional toilet with a water-saving-type toilet is one of the most effective solutions for reducing domestic water use.

KEYWORDS domestic water use; projection; Tokyo; water related appliances; water saving

INTRODUCTION

The amount of water supply per capita in Japan increased with economic growth until reaching a plateau in the 1990s, and has since decreased over the last 4–5 years (Ministry of Land, Infrastructure, Transport and Tourism, 2008). The amount of domestic water use per capita in Tokyo also shows a gradual decrease over the last 6–7 years, as shown in Figure 1 (Tokyo Waterworks Bureau, 1980–2008). One reason for this trend is that newer appliances with advanced water saving technology, such as dishwashers and water-saving washing machines, have been developed and supplied to the market in which the usage rates of basic water-related appliances, such as flushing toilets and private baths, have approached a degree of saturation.

The domestic water use per capita is known to be influenced by various factors, such as water charges, household income, household size, climate, precipitation, consciousness about water saving and so on (Aramaki *et al.*, 2004; Yamada *et al.*, 2004; Murase *et al.*, 2005). For example, the pattern of domestic water use has been analyzed according to household size (Yamada *et al.*, 2004). The relationship between water charge and domestic water use has also been analyzed (Murase *et al.*, 2005). However, the models in previous papers have not considered the decreasing trend of domestic water use per capita. It is most likely that the use of advanced water-saving appliances has greatly influenced the downward trend of domestic water use per capita in recent years because the use reduction achieved by these appliances is significant. This trend was also seen in a study of water use in California (CALFED Bay-Delta Program, 2006).

The present study undertook a projection of domestic water use in Tokyo, incorporating simulated usage of a range of water-related appliances including advanced water-saving appliances. In other words, the decreasing trend of domestic water use per capita in recent years was expressed by modeling the introduction of advanced water-saving appliances. The amount of domestic water use per capita was calculated according to the proposed model from 1998 to 2006 and compared with Tokyo's actual data (Figure 1) for that time period setting the parameter at the base year of 1997. The parameters were then used to project water use until 2050.

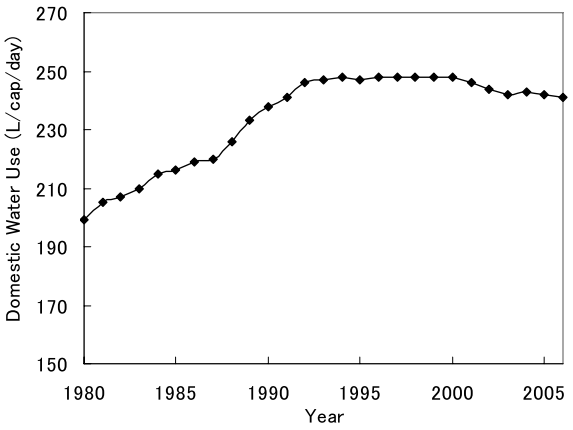

Figure 1. Changes in domestic water use per capita in Tokyo.

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METHODOLOGY

Estimation of future domestic water use in Tokyo

The domestic water use per capita in Tokyo reached a plateau in 1997, at 248 L/cap/day (Tokyo Waterworks Bureau, 1980–2008). Its subsequent reduction was assumed to result from new water-saving appliances being used in households. Based on this assumption, the amount of water use per capita was calculated for each purpose, classified into kitchen (cooking and dish washing), laundry, toilet, bathing and 'face wash and others' usage. Then, the projected future domestic water use per capita was estimated as the total amount of water consumed for each purpose as shown in Eq. (1).

$$\text{Domestic water use (L/cap/day)} = \sum_{i=1}^{n}[\{b_i \times (1 - a_i) + (1 - b_i)\} \times Q_i] \quad (1)$$

where, i is the purpose of water use in household, a_i is the saving rate of each water-saving appliance, b_i is the usage rate of each water-saving appliance, Q_i is virtual maximum water use for each water use category assuming the water-saving appliances are not used.

The values for a_i are shown in Table I. The saving rate a_i of dishwasher, 24 hours bath, water-saving-type shower, and water-saving tap plug indicate the reduced amount of water for each purpose after introducing these water-related appliances. The saving rate a_i of full automatic washing machine and drum-type washing machine indicate the difference compared to the conventional water tank type washing machine. The saving rate a_i of 10 L-type toilet, 8 L-type toilet, and 6 L-type toilet indicate the difference compared to the conventional 13 L-type toilet. The amount of water use is increased by introducing bidet with a fountain of warm water. Therefore, the domestic water use per capita is assumed to increase 1 L/day when the bidet with a fountain of warm water is introduced.

In order to obtain b_i, past records of usage rates of conventional and water-saving appliances for household water use were used in order to project future trends of usage. Figure 2 shows the domestic usage rates of conventional and water-saving appliances obtained from the field survey of domestic water use that is conducted by the Tokyo Waterworks Bureau every three years. Usage rates shown in this figure for conventional appliances, that is bathtubs, showers, washing machines and flushing toilets, were nearly 100%. Changes in water use occurred due to the use of dishwashers, fully automatic washing machines, 10 L low-flush toilets (10 L indicates 10 liters of water per flush), '24-hour baths' (these are defined as systems offering purification, disinfection, heat insulation, and circulation), water-saving tap plugs and bidets, and each of these were considered in this analysis. The water-saving appliances for which usage rates have been increasing include fully automatic washing machines, dishwashers, and toilets which incorporate a bidet (for washing with a fountain of warm water). Future trends of usage for these appliances were projected by a logistic function using the least-square method. Saturation values of the logistic curve for the usage rate of each water-related appliance were tentatively assumed as shown in Table II considering information about past condition of usage rate. The usage rates of these water-related appliances were obtained from a website (Association of 24 hours bath system, 2008) and an interview survey. According to an interview survey

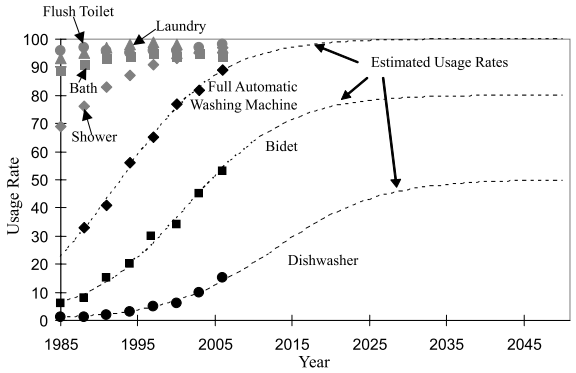

Figure 2. Usage rates of water-related appliances and projected usage rates (Tokyo Waterworks Bureau, 1980–2008).

Table I. Water-saving rate of appliances.

Purpose	Water-related appliances	Saving rate (%)	Source
Kitchen	Dishwasher	80	(Nagasaki Prefecture Government, 2009)
Laundry	Full automatic washing machine	14	(Takada *et al.*, 2005)
	Drum-type washing machine	33	(kain, 2008)
Bath, Shower	24 hours bath	50	Interview survey at the association of 24 hours bath system
	Water-saving-type shower	20	(Nagasaki Prefecture Government, 2009)
Toilet	10 L-type toilet	23	Interview survey at TOTO LTD
	8 L-type toilet	38	Interview survey at TOTO LTD
	6 L-type toilet	53	Interview survey at TOTO LTD
	Bidet with a fountain of warm water	1 L increase*	(Nagasaki Prefecture Government, 2009)
Face wash and others	Water-saving tap plug	50	(Tokyo Waterworks Bureau, 2008)

* '1 L increase' means domestic water use per capita is assumed to increase 1 L/day when the bidet with a fountain of warm water is introduced.

Table II. Saturation usage values for the logistic function of each water-related appliance used in the model.

Purpose	Water-related appliances	Saturation usage value (%)
Kitchen	Dishwasher	50
Laundry	Full automatic washing machine	100
Bath, Shower	24 hours bath	5
Toilet	10 L-type toilet	80
	6 L-type toilet	80
	Bidet with a fountain of warm water	80
Face wash and others	Water-saving tap plug	50

at TOTO Ltd., the usage rate of water-saving toilets has reached about 60% over 30 years. Therefore, the usage rate of a 10 L-type toilet was assumed to be 60% following its introduction to the market in 1994. The future trends for these appliances were also projected by a logistic function with the least-square method as shown in Figures 3(a) and 3(b). Moreover, other water-related appliances, such as drum-type washing machines and water-saving showers have been introduced. However, these appliances were not considered due to their low usage rate and because their use is not currently increasing rapidly.

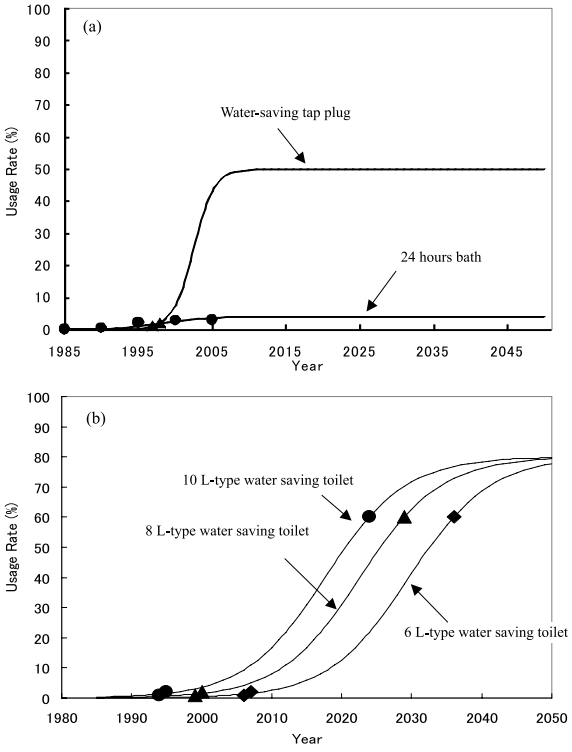

Figure 3. (a) Projected usage rates of 24-hours bath and water-saving tap plug (24-hours Bath System, interview survey at TOTO Ltd.) (b) Projected usage rates of the 6 L, 8 L, and 10 L-type water-saving toilets (6 L, 8 L, and 10 L means the amount of water per flush)

Q_i was determined by the water used per capita for each purpose in 1997 (kitchen, 55.6 L; laundry, 54.2 L; toilet, 59.7 L; bath, 65.3 L; and hand basin and other usages, 20.0 L). Water use for cooking was assumed not to change.

RESULTS AND DISCUSSION

The first projection of domestic water use per capita based on equation (1) is shown in Figure 4. Compared to the actual domestic water use in Tokyo between 1998 and 2006, as obtained from the Tokyo Waterworks Bureau, the calculated amount of the domestic water use per capita per day is accurate to within plus or minus 1%, as shown in Figure 5. According to the model expressed by equation (1), the reduction rate from the maximum water demand in 1997 is projected to be 9% in 2025 and 10% in 2050. A breakdown of the projected domestic water use figures for 2025 and 2050 is shown in Table III.

It is expected that water use for baths and toilets will be substantial in Japan, even in the future, according to past trends of usage rates. It is difficult for people to reduce water usage for bathing from a hygienic point of view. On the other hand, reducing water used in the toilet will contribute to reducing the level of domestic water use in the future.

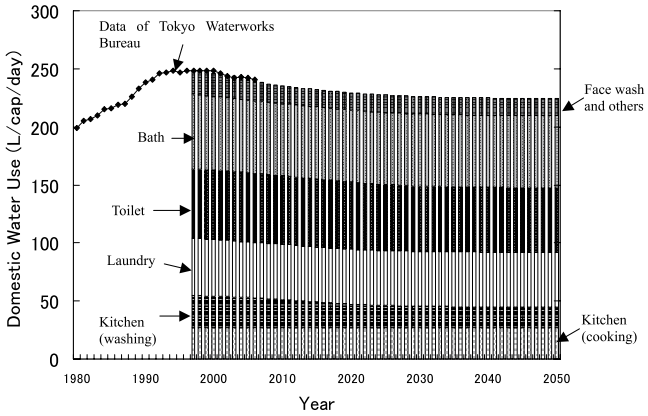

Figure 4. Results of the projection of domestic water use per capita per day.

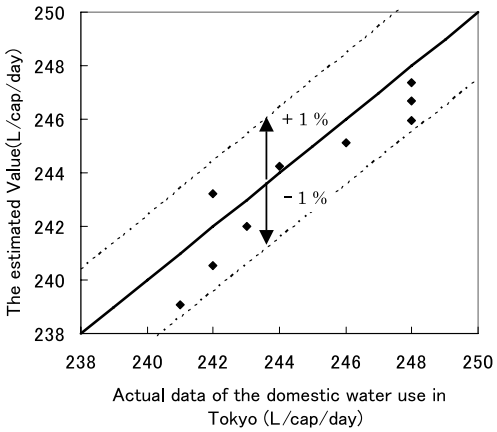

Figure 5. Comparison of the actual data of the domestic water use in Tokyo and the estimated values.

Table III. Breakdown of projected domestic water use.

	Kitchen (cooking)	Kitchen (washing)	Laundry	Toilet	Bath	Face wash and others	Total
Amount of water use in 1997 (L/cap/day)	27.3	27.3	49.5	59.5	64.5	19.8	247.9
Projected water use in 2025 (L/day/cap)	27.3	18.9	47.3	56.4	62.1	14.9	226.8
Reduction rate	0.0%	30.7%	4.7%	5.3%	3.7%	24.9%	8.5%
Projected water use in 2050 (L/day/cap)	27.3	17.4	47.2	55.0	62.1	14.9	223.9
Reduction rate	0.0%	36.1%	4.8%	7.5%	3.7%	24.9%	9.7%

Therefore the second simulation was performed by replacing the 10 L-type toilet with a 6 L-type toilet, and the results are shown in Figure 6. It was found that if the 6 L-type toilet is adopted in Japan according to the projected usage rate as shown in Figure 3 (b), a take-up rate which could be achieved through advertising campaigns and water policy, the domestic water use per capita per day would reduce to around 200 L. In this case the reduction rate is then projected to be 11% by 2025 and 17% by 2050, with 1997 set as the base year.

Here, the market saturation values of first projection shown in Table II were tentatively set from past conditions of usage rate. If the usage rate of 6 L-type toilet, dish washer, and water-saving tap plug will be 100% and the drum-type washing machine with high saving rate (as shown in Table I) will be replaced with the full automatic washing machine as shown in Table IV in the assumption of a scenario where aggressive water saving is accompanied by water conserving policy until 2050, then the total amount of domestic water use would reduce to 171.2 L/cap/day as shown in Table IV. In this case, the water use for toilet and kitchen were significantly reduced; and the reduction rate is projected to be 31% by 2050, with 1997 set as the base year. Therefore it is considered that high efficient water use can be achieved without compromising sanitary living standards, by implementing above-mentioned water-saving appliances.

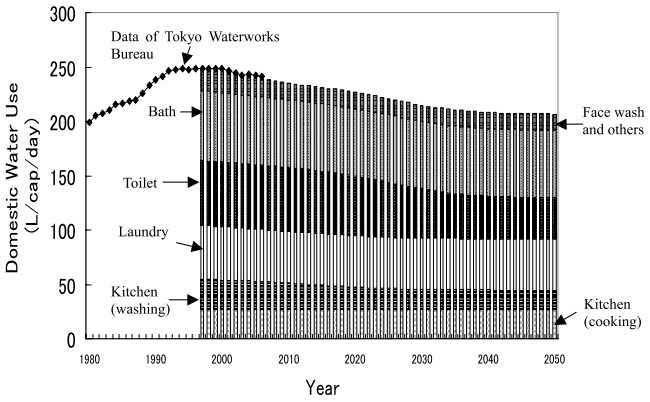

Figure 6. Results of the projection of domestic water use per capita with the 6 L-type toilet instead of the 10 L-type toilet.

CONCLUSIONS

This paper aims to quantify the amount of domestic water use needed in the future by estimating usage rates of various water-related appliances. Tokyo Metropolis was selected as a case study. The results of this study show that the calculated amount of domestic water use reproduced the actual amount of water use between 1998 and 2006 accurately and the reduction rate is projected to be 9% by 2025 and 10% by 2050 with 1997 set as the base year. The model was developed to reflect the present market uptake trends of water-related appliances. In addition, it was considered that the amount of water used for flushing toilets would be substantial even in the future. From the results of a simulation performed by replacing the 10 L-type toilet with a 6 L-type toilet, it was found that the domestic water use per capita per day would reduce to around 200 L. The replacement of a conventional toilet with a water-saving-type toilet is hence one effective solution for reducing domestic water use in the future.

ACKNOWLEDGEMENTS

This paper presents the results of the research

Table IV. Breakdown of projected domestic water use with aggressive water saving accompanied by water conservation policy.

	Kitchen (cooking)	Kitchen (washing)	Laundry	Toilet	Bath	Face wash and others	Total
Water-related appliances	–	Dish washer	Drum-type washing machine	6 L-type toilet	24 hours bath	Water-saving tap plug	
Saturation usage value	–	100	100	100	5	100	
Amount of water use in 1997 (L/cap/day)	27.3	27.3	49.6	59.5	64.5	19.8	247.9
Projected water use in 2050 (L/day/cap)	27.3	5.8	37.8	28.2	62.1	10.0	171.2
Reduction rate	0.0%	78.8%	23.8%	52.6%	3.7%	49.5%	31.2%

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REFERENCES

Aramaki T, Suzuki M, Hanaki K. 2004. International analysis and projection of domestic water use. *Journal of Global Environment Engineering* **10**: 1–10.

Japan, Association for 24 hours bath system. April 1, 2008. *Number of shipments*. http://24furo.v.wol.ne.jp/database/04/index.htm. [June 16, 2009] (in Japanese).

Japan, Ministry of Land, Infrastructure, Transport and Tourism. August 21, 2007. *Transition of the amount of water usage for life*. http://www.mlit.go.jp/tochimizushigen/mizsei/c_actual/images/03-02.gif. [June 7, 2009] (in Japanese).

Japan, Nagasaki Prefecture Government. May 28, 2009. *Results of the field survey of water-saving appliances*. http://www.pref.nagasaki.jp/suido/download/pdf/riyou06.pdf. [June 7, 2009] (in Japanese).

Japan, Tokyo Waterworks Bureau. June 8, 2009. *How to use water efficiently*. http://www.waterworks.metro.tokyo.jp/customer/life/g_jouzu.html. [June 7, 2009] (in Japanese).

Japan, Tokyo Waterworks Bureau. *Annual documents of domestic water use in Tokyo*. 1980–2008. http://www.waterworks.metro.tokyo.jp/customer/life/g_jouzu.html. [June 7, 2009] (in Japanese).

Japan. kain. May 16, 2009. *The amount of the water used of a washing machine*. http://www.seikatu-cb.com/kiwami/siyous01.html. [June 7, 2009] (in Japanese).

Murase M, Nakamura A, Kawasaki H. 2005. An analysis for demand structure and price of domestic water supply. *Proceedings of Hydraulics Engineering*. JSCE. **49**: 475–480 (in Japanese).

Takada J, Tasaka H, Usui S. 2005. Actual water consumption according to the purpose in an ordinary house. *The Collected Lectures of the 56th National Symposium on Water Supply Technology*. 66–67 (in Japanese).

Yamada K, Tanaka K, Sato Y, Higashi Y. 2004. The structure analysis of domestic water demands according to the size of the households. *Proceedings of Environmental System*. JSCE. **32**: 403–406 (in Japanese).

USA, CALFED Bay-Delta Program. 2006. *Water Use Efficiency Comprehensive Evaluation Final Report*. http://www.calwater.ca.gov/content/Documents/library/WUE/2006_WUE_Public_Final.pdf. [June 7, 2009]