Analysis of Decreasing Tendency of Domestic Water Use per Capita in Tokyo

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Abstract

In this study, the decreasing trend of the amount of domestic water use per capita in recent years was analyzed and expressed by modeling the introduction of advanced water-saving appliances. The amount of water supply per capita in Japan increased with economic growth reached a plateau in the 1990s and then has decreased over the last 5-6 years. The amount of domestic water use per capita in Tokyo also shows a gradual decrease over the last 7-8 years. By analyzing this trend, it found that one of the reasons 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 under the condition in which the usage rates of basic water-related appliances, such as flushing toilets and private baths, have approached a degree of saturation. In this study, the amount of domestic water use was also quantified by estimating the usage rates of various water-related appliances by analyzing the decrease trend. Tokyo Metropolis was selected as a case study. New model was proposed for the projection of domestic water use in Tokyo, incorporating simulated usage of a range of water-related appliances including advanced water-saving appliances. The amount of domestic water use per capita was calculated according to the proposed model from 1998 to 2007 and compared with Tokyo's actual data for that time period setting the parameter at the base year of 1997. The results show that the calculated amount of domestic water use reproduced the actual amount of water use between 1998 and 2007 accurately and the reduction rate is projected to be 12 % by 2025 and 18 % by 2050 with 1997 set as the base year.
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Keywords: domestic water use, Tokyo, water related appliances,water saving

Introduction

Domestic water use per capita in Japan increased with economic growth reached a plateau in the 1990s and then has decreased over the last 5–6 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 7–8 years, as shown in Figure 1 (Tokyo Waterworks Bureau, 1980–2007). 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 under the condition 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, T. *et al.* 2004;. Yamada, K. *et al.* 2004; Murase, M. *et al.* 2005). For example, the pattern of domestic water use has been analyzed according to household size (Yamada, K. *et al.* 2004).The relationship between water charge and domestic water use has also been analyzed (Murase, M. *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 (California Urban Water Conservation Council, 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. In order to identify the parameters of the proposed model set at the base year of 1997, calculated domestic water use per capita from 1998 to 2007 was compared with actual data. The parameters were then used to project until 2050.

Modelling scheme

The domestic water use per capita in Tokyo reached a plateau in 1997, at 248 L/cap/day (Tokyo Waterworks Bureau, 1980–2007). 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).

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

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 1. 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. 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.

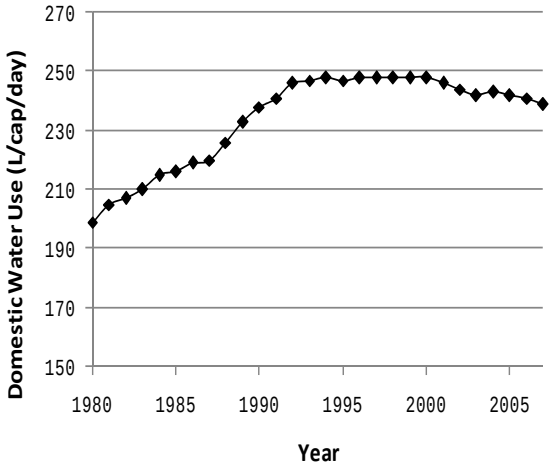

Figure 1. Changes in domestic water use per capita in Tokyo

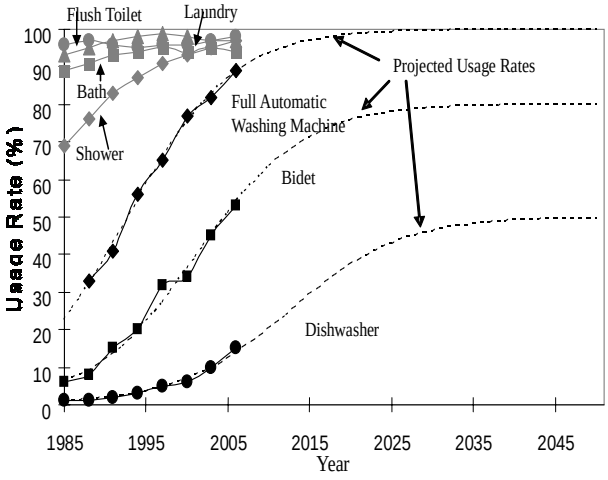

Figure 2.Usage rates of water related appliances and projected usage rates (Tokyo Waterworks Bureau, 1980–2008)

Table 1. 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	(Association for 24 hours bath system,2008)
	Water-saving-type shower	20	(Nagasaki prefecture government,2009)
Toilet	6 L-type toilet	53	Interview survey at TOTO LTD, (Association for Japanese sanitary equipment,2008)
	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 installed)

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, 6 L low-flush toilets(6 L means the amount 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: all 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 2 considering information about past trends. The usage rates of these water-related appliances were obtained from the website (24-hour bath council website, 2008) and an interview survey. From an interview survey at TOTO Ltd., the usage rate of water-saving toilets will reach about 70 % over 30 years. Therefore, the usage rate of 6 L-type toilet was assumed to be 70 % following its introduction to the market in 2006. 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) (24-hours Bath Council, The Tokyo Waterworks Bureau, Interview survey at TOTO Ltd., Association for Japanese sanitary equipment,2008). 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 the lack of information on rates of market uptake.

Table 2. 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	6 L-type toilet	80
	Bidet with a fountain of warm water	80
Face wash and others	Water-saving tap plug	50

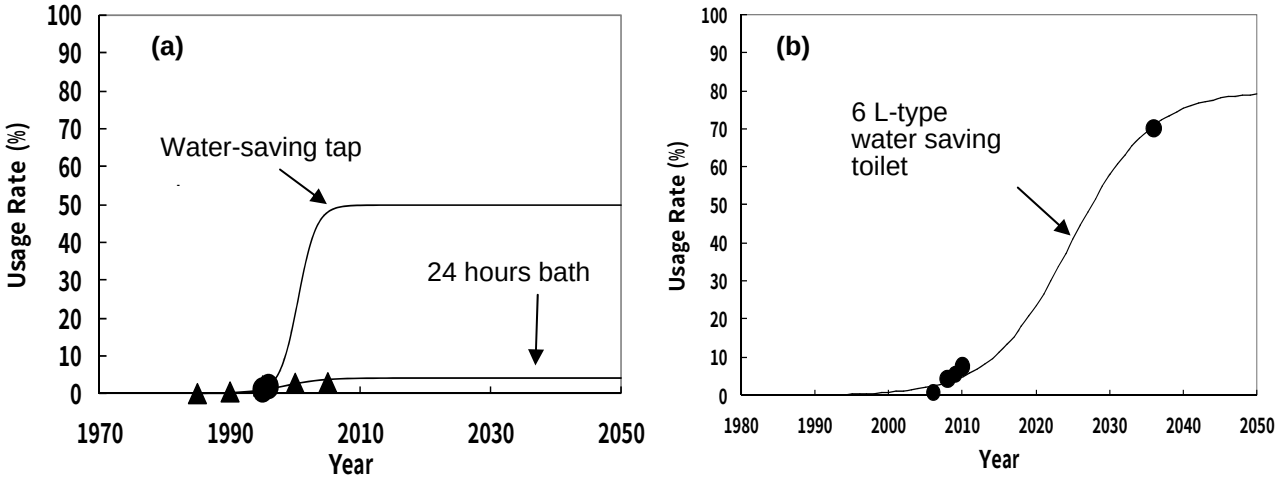

Figure 3. **(a)** Projected usage rates of 24-hours bath and water-saving tap plug (24-hours Bath Council, The Tokyo Waterworks Bureau)
(b) Projected usage rates of the 6 L-type water-saving toilets (6 L means the amount of water per flush)
(Interview survey at TOTO Ltd.,2008, Association for Japanese sanitary equipment,2009)

Results and discussion

The projection of domestic water use per capita based on the equation (1) is shown in Figure 4. Compared to the actual domestic water use in Tokyo between 1998 and 2007, 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 12 % in 2025 and 18 % in 2050. A breakdown of the projected domestic water use figures for 2025 and 2050 is shown in Table 3.

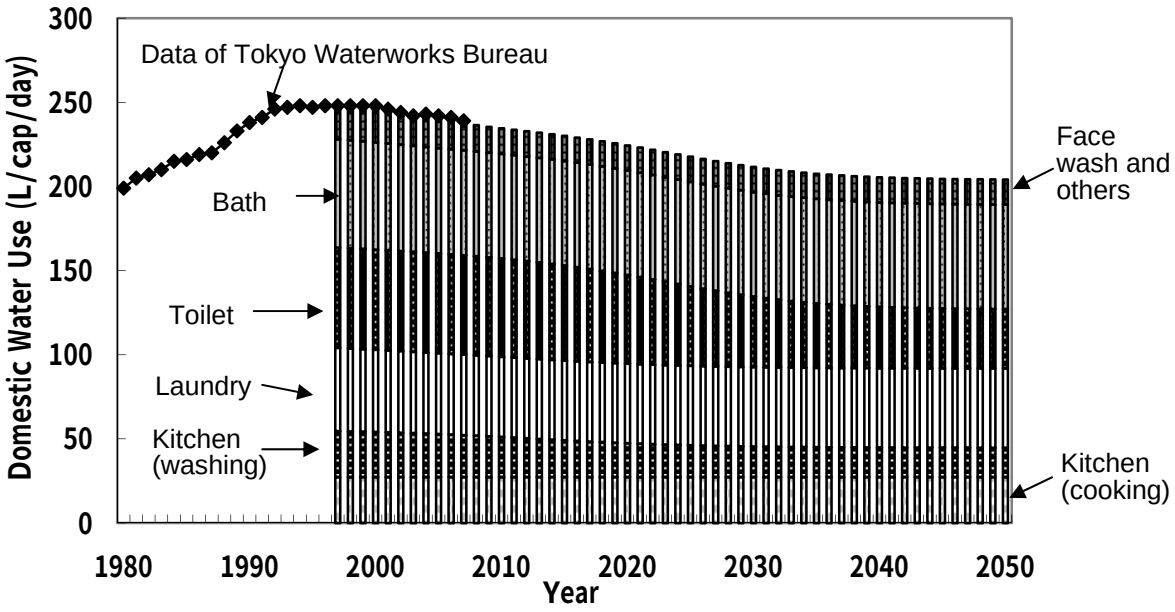

Figure 4. Results of the projection of domestic water use per capita per day.

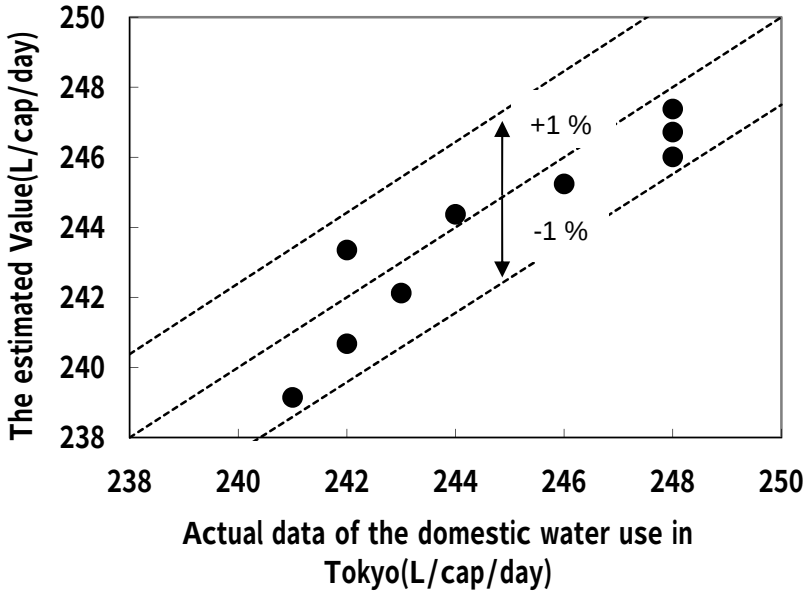

Figure 5. Comparison of the actual data of the domestic water use in Tokyo and the estimated values.

Table 3. 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	47.2	62.1	14.9	217.7
Reduction rate	0.0%	30.7%	4.5%	20.6%	3.7%	24.8%	12.2%
Projected water use in 2050(L/day/cap)	27.3	17.4	47.2	35.2	62.1	14.9	204.2
Reduction rate	0.0%	36.1%	4.6%	40.8%	3.7%	24.8%	17.6%

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 probably 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 might contribute to reducing the level of domestic water use in the future. Therefore , the usage rates of 6-L type water saving toilet is rapidly increasing recently as shown in Figure3.(b) to reduce CO_2 emission by reducing the water consumption.

Here, the market saturation values shown in Table 2 were tentatively set from past trend. If the usage rate of 6L type toilet, dish washer, and water saving disk will be 100 % and the drum-type washing machine with high saving rate(as shown in Table 1) will be replaced with the full automatic washing machine as shown in Table 4 in the assumption of a scenario where aggressive water saving is accompanied by water conserving policy until 2050, the total amount of domestic water use would reduce to 171.2 (L/cap/day) as shown in Table 4. In this case, the water use for toilet and kitchen were significantly reduced. Therefore it is considered that a society with efficient water use can be developed without compromising sanitary living standards, by implementing these water saving appliances.

Table 4. 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%

Conclusions

In this study, the decreasing trend of the amount of domestic water use per capita in recent years was analyzed and expressed by modeling the introduction of advanced water-saving appliances. Tokyo was selected as the city for a case study. The results show that the calculated amount of domestic water use reproduced the actual amount of water use between 1998 and 2007 accurately and the reduction rate is projected to be 12 % by 2025 and 18 % 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. 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.

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