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Micro-components survey of residential indoor water consumption in Chiang Mai

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Abstract. The direct measurement of the micro-components of water consumption (i.e., consumption by each residential activity, such as toilet-, laundry-, bath-, and kitchen-use), both in the dry season and in the rainy season, was conducted in Chiang Mai, Thailand. It was expected that rainfall differences between the dry and rainy season would influence awareness for water resources so that water consumption in the dry season would be smaller than that in the rainy season. In addition, it was examined whether the differences in water resources such as public waterworks or non-public waterworks (i.e., community waterworks, mountainous water and groundwater), affected the amount of water use. A small-sized accumulative water meter was developed for measurement. This survey provides important information for water demand estimations and water supply planning in middle-developed countries where water consumption is expected to increase in future.

1 Introduction

Generally, water consumption increases per capita proportional to GDP growth. According to historical data in developed countries, it stops increasing or begins to decrease when it reaches a plateau (Bengtsson, 2005). Most of the developed countries have already reached such a plateau. In the case of middle-developed countries, such as Thailand, economic growth is currently remarkable. And in the near future, water consumption may increase and the lifestyle and water use pattern may change to a large extent. For purposes of water demand estimations and water supply planning in such countries, it is important to know not only the total water consumption per capita, but the micro-components of water consumption (i.e., consumption by each residential activity, such as toilet-, laundry-, bath-, and kitchen-use). For example, toilet use depends on equipment to a considerable extent, but kitchen use does not. Thus, such detailed knowledge regarding water consumption leads to more practical and accurate demand estimations.

Much research has been conducted to gain knowledge on the micro-components of water consumption in developed countries. For example, Fig. 1 shows the results of residential indoor use (Otaki, 2003). Patterns of water use differ city-by-city, however, and the city with a larger consumption level is not always the greater user with respect to every component. For example, although total consumption in Singapore is relatively small, its consumption for baths is the second largest amount among surveyed developed cities.

As there have not been enough studies about micro-components in countries other than developed ones, this paper studies and measures micro-components of indoor water use in the middle-developed country of Thailand. Economic growth within Thailand has been significant in the past several years, and its water consumption should be expected to increase from here on. Therefore, Thailand is one of the important countries for which we have to consider the water demand estimations and water supply planning.

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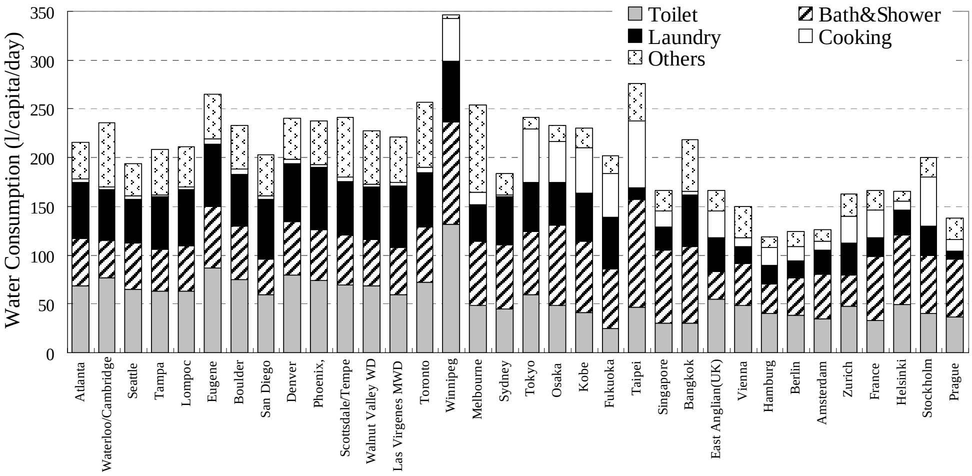

Figure 1. Micro-components of residential indoor use.

2 Methodology

2.1 Development of the device for measuring water consumption

In the case of developed countries, methodologies for measuring water consumption are classified into three groups. The first one is the direct measurement of the water used. For example, Tokyo's municipality in Japan adopted this method and set meters to each tap in seventy-six households for one year. The shortcomings in this study were the limited number of samples, and the necessity for the use of numerous meters (4–6 m per household) involving the need for cooperation from each household. Despite all this, however, the method used in Tokyo was able to obtain real and accurate data.

The second method for measuring water consumption obtained estimations through interviews. Each micro-component was determined by gathering information on ownership of appliances, frequency of use, and the volume of water per use. The Environmental Agency (UK) used this method and estimated data were used for water demand forecasting. Fukuoka (Japan) and Bangkok (Thailand) also used this method and collected information from 100 and 814 interviews, respectively (Little, 1996). Although the data is an "estimated" value, it is easy to obtain many samples.

The third method for measuring water consumption is to collect time-series data of total residential water consumption and to calculate it for each component by the water flow pattern. The American Water Works Association (AWWA), Osaka (Japan), and the East Anglia Region (UK) adopted this method (AWWA, 1999; Yamanishi, 2002; Edwards, 1995). This method is convenient for both the user and the experimenter, because there is no need to set meters to each tap. The only real problem is the cost.

In some developing countries such as Thailand, people usually collect water in large containers to cope with the lack of water pressure, the intermittent water supply and the impurities within the water. Thus, the time-series data method (third one) is not suitable. For surveys in such countries, we have to choose from the direct measurement method (first one) or the interview method (second one). In the case of interview surveys in developing countries, the reliability of the estimated water consumption may not seem high because people are apt to exaggerate their water use abilities. Therefore, we decided to collect the data by direct measurement.

To measure the water consumption from each tap, we developed a small-sized accumulative water meter, 5.5 cm in length, with a diameter of 1.7 cm (Fig. 2). The small water flow meter (Turbine meter Vision 2000-4F22, GRAZ Co., Ltd.) was set to the tap end, and its pulse (1000 pulse/L) was monitored by a pulse counter (OMRON). This meter is so small that tap users do not experience any inconvenience. Four D size alkaline batteries supplied power to the sensor. This device can monitor water flow continuously for two months.

2.2 Selection of Chiang Mai

A list of provinces with the top ten populations in Thailand (Table 1) indicates a higher concentration of people in the province of Bangkok. Although Bangkok is the largest and most represented city in Thailand, we considered it unsuitable for our research. The reasons are as follows. First, Bangkok is already a developed city to some extent, so it did not fit within our research parameters to collect data for regions consisting of middle-developed economic conditions. Secondly, the Metropolitan Waterworks Association (MWA) had already finished the questionnaire survey in Bangkok in 1996 (Little, 1996). This result is shown in Table 2. Thus, from the list of the top ten cities in Thailand, we choose

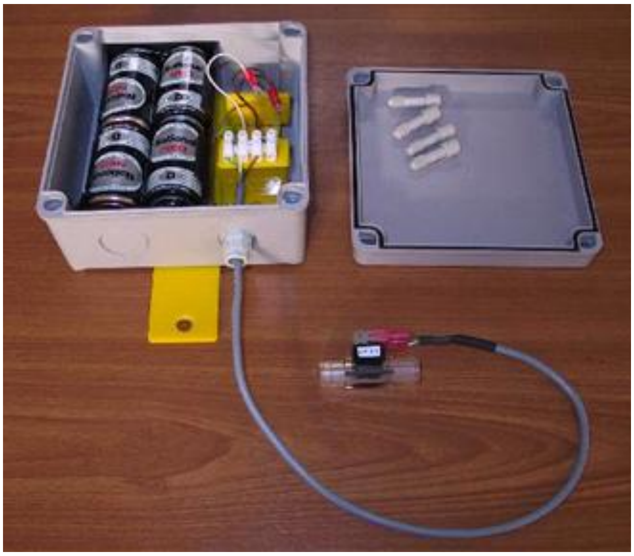

Figure 2. Small-sized accumulative water meter.

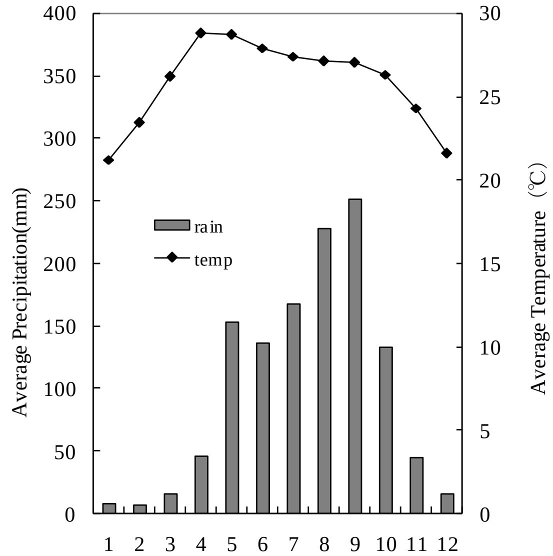

Figure 3. Monthly average temperature and rainfall in Chiang Mai.

Table 1. Top 10 population by province.

Province	Population 2003
Bangkok	5 844 607
Nakhon Ratchasima	2 591 050
Ubon Ratchathani	1 805 322
Khon Kaen	1 770 605
Chiang Mai	1 603 220
Buri Ra	1 554 009
Udon Thani	1 542 071
Nakhon Si Thammarat	1 531 072
Si Sa Ket	1 465 538
Surin	1 406 612

National Statistical Office 2004

Table 2. Micro-components of residential use in Bangkok.

Total	L/p/d
Toilet	31
Bath & Shower	78
Laundry	52
Kitchen	4
Loss	24
Others	28

Chiang Mai, the central city of the country's northern area, as our study area.

Chiang Mai is located about 70 km north of Bangkok. Approximately 1.6 million people live in Chiang Mai province, and 0.25 million people live in the city area known as Muang Chiang Mai. Its climate is classified as tropical monsoon and can be divided into three seasons: rainy season (May to November), dry season (November to March), and the hot season (March to May). Figure 3 plots the monthly average temperatures and rainfall in Chiang Mai. This survey was conducted during the rainy season, from 7 January 2004 to 1 March 2004, and the dry season, from 28 July 2004 to 5 September 2004. Although there are many reports that indicate how temperature differences affect water consumption, there has been no research which compares the consumption between the rainy season and the dry season. Most households in Chiang Mai have enough water resources other than rainfall, thus water is not lacking even during the dry season. However, it was expected that the lack of rainfall during the dry season would make people more aware of water supply conditions and thus, they would consciously try to avoid wasting water.

2.3 Survey procedure

At first, we delivered the questionnaire sheet to approximately 160 households based on household income levels. Then, we visited these households and checked the availability of meter settings. Usually, there were two to eight taps per house for indoor use. Most of the taps were located inside the house, and some taps, usually those for laundry, were located outside of the house. Finally, we selected 63 households, set the meters to each tap of each household for about one month, and calculated the average daily water consumption per capita. Basically, the measurement was done for the same households in both dry and rainy seasons. The survey in dry season was conducted for 63 households. In rainy season it was conducted for 55 households, because, unfortunately, some households were absent during the meter setting

Figure 4. Equipment for divarication.

Figure 5. Rainwater collection.

period. In cases where one tap was used for various activities, we used the equipment for divarication (Fig. 4) to divide activities. What was more commonly the case was that water from one tap was used for both toilet and bath use. In cases where it was impossible to divide activities, we exempted that particular tap from the survey and measured only the amount of the end-use that was determinable. This was done because it was desirable to get as much data as possible in order to understand the distribution of micro-components use. Thus, not all indoor activities were always measured in all households. For example, in some households, all activities were measured (toilet, bath, laundry, and kitchen), whereas in other households only the toilet and kitchen water was measured. The consumption for flush toilets was calculated from the flush tank volume multiplied by the number of times it was flushed, which was counted by a pedometer.

3 Results and discussion

3.1 Brief overview of current water supply in Chiang Mai

Public waterworks operated by the Provincial Waterworks Association (PWA), supplied water to 18% of the central area of Chiang Mai in 2002. A water resource for public waterworks is the Pin River. The monthly water bill averages 132.39 baht compared to the average monthly power bill of 488.83 baht (Mathurasa, 2005). This was not because of cheap water fare only, but because of parallel usage of public waterworks and other water resources, such as rainfall or mountainous water, which make up a part of the small community's water system and whose resource is directly from the mountain, etc. People who lived in other areas used community waterworks, mountainous water and groundwater.

Regardless of the type of water resources, the water supply network inside a house is almost the same. In the case of community water and mountainous water, each household connects to the main pipe and water runs through the water supply network inside the house and flows to the tap. In the case of ground water, each household pumps up the ground water and water runs through the water supply network inside the house and flows to the tap as well. In the case of rainwater, it is collected and settled in large container (Fig. 5). The collected water flows from the tap connected to the container. In the dry season survey, 45 households primarily used public waterworks, and 18 households used other resources. Similarly, the rainy season survey revealed that 39 households mainly used public waterworks, and 16 households used other resources.

Figure 6. Pail toilet.

3.2 Water consumption for toilets

The typical toilet in Thailand consists of a pail and a squat toilet. People flush water down the toilet by using the pail (Fig. 6). 87% of households in this research study used the pail and squat toilet and 13% used flush toilets. Normally, the water consumption of the pail and squat toilet was less than that of the flush toilet (White, 2004). Thus, water consumption for toilets may be less than that in developed countries. In the case of the pail toilet, where the water required is done by hand, we surmised that there would likely be no difference between the amounts used during the rainy and the dry season. Furthermore, surmised that water use in the dry season would be less because of psychological factors related to the lack of available water.

Figure 7 indicates the histogram of water consumption for toilet use in the dry and the rainy seasons. Most households used under 30 L/p/d. According to the Kolmogorov-Smirnov test (KS-test), there was no significant difference (significant level >0.05) between water consumption for toilet use in the dry and rainy seasons. The median of the dry season, 15 L/p/d, is more than that of the rainy season, 11 L/p/d, a finding which was opposite to our estimation. More than 60% of observed data was distributed under 20 L/p/d, and more than 80% was distributed under 30 L/p/d. In the case of developed countries, the least amount was 25 L/p/d in Fukuoka, and 31 L/p/d in Singapore. Compared to these figures, consumption in Chiang Mai was considerably less, because of mainstream use of the pail toilet. Compared to Bangkok, 27 L/p/d, consumption in Chiang Mai was less, too. In 1996, when the survey was carried out in Bangkok, the percentage of people using pail toilets in Bangkok was 80% (Little, 1996) and 87% in Chiang Mai. Since these percentages are similar, toilet consumption differences in Bangkok and Chiang Mai are not because of the types of toilets, that is the pail toilet or the flush toilet.

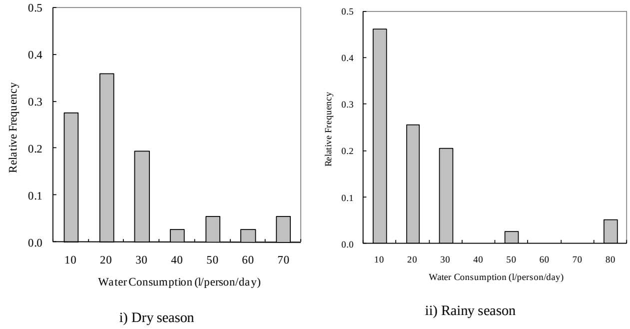

Figure 7. Histogram of per capita consumption for toilet.

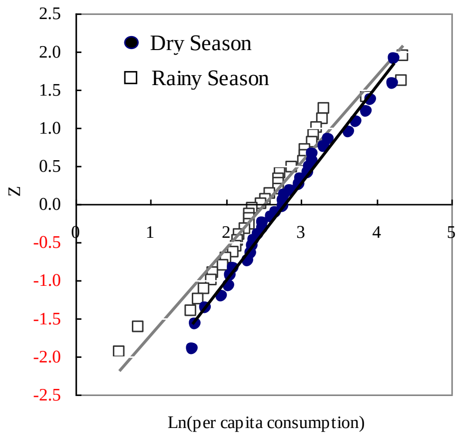

Figure 8. Distribution of water consumption for toilet.

According to Fig. 8, water consumption per capita for toilets appears distributed through log-normal distribution. It means that the distribution of the values before conversion for logarithm is considered to be a normal distribution. A gentle slope means a large dispersion, and the intersection with the x-axis is the central value of distribution. R2 values of linearr regression are 0.996 for the dry season and 0.991 for the rainy season. This is verified by the Shapiro-Wilk W-test (significant level >0.05). This tendency was found in previous studies on water consumption (Roseberry and Burmaster, 1992). Therefore, this supports the reliability of our methodology and collected data. The water consumption for toilet use of households that use municipality water and ground/community water are compared in Fig. 9. Judging from the KS-test, the difference of water resources and public waterworks does not result in consumption differences.

3.3 Water consumption for laundry

In Chiang Mai, most of the households use washing machines, but some households still do not have washing machines and wash their clothes by hand. Therefore, both machine-washing and hand-washing amounts have to be measured for laundry use. The most popular type of washing

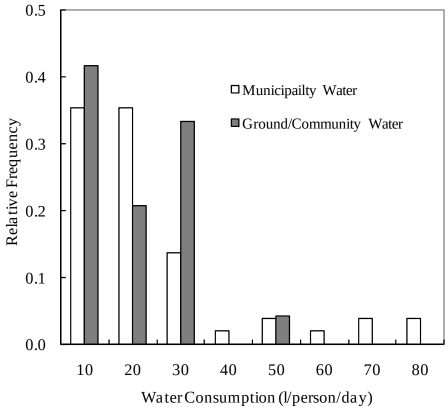

Figure 9. Comparison of municipality water user and ground/ community water user.

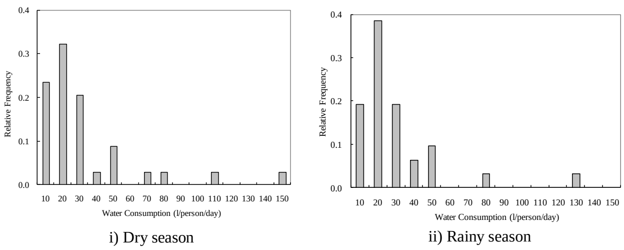

Figure 10. Histogram of consumption per capita for laundry.

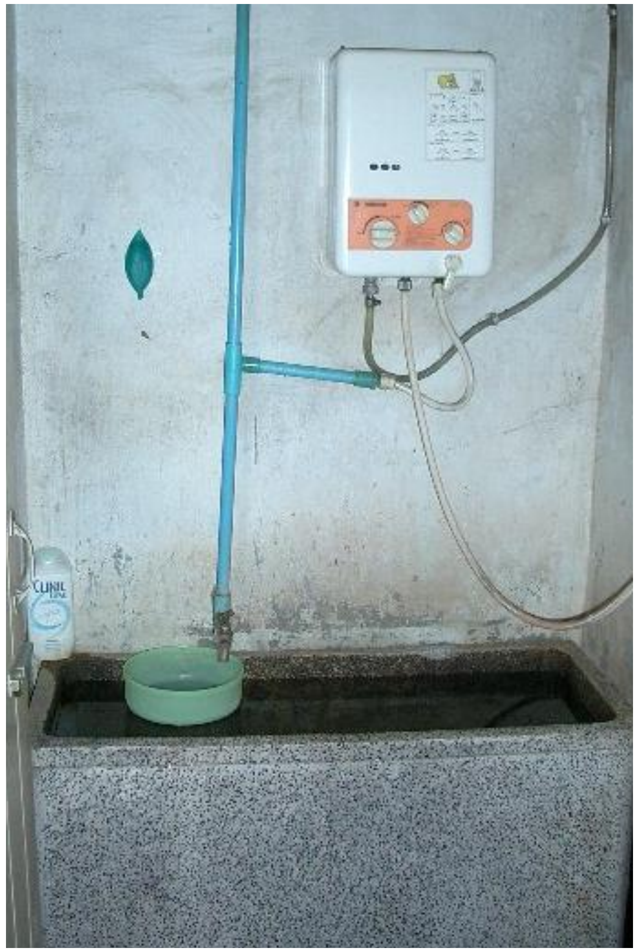

Figure 11. Typical bath room in Thailand.

machine is the twin-tub washing machine, thus, there is a possibility that people reduce water use in the dry season because of psychological factors (i.e., they are influenced by less water around them).

Figure 10 indicates the histogram of water consumption for laundry use in the dry and rainy seasons. Most households used under 30 L/p/d. According to the KS-test between these two histograms, there is no significant difference (significant level >0.05) between the water consumption for laundry use in the dry season and rainy season. An intermediate value also reveals no difference between the dry season, 18 L/p/d, and the rainy season, 19 L/p/d. Therefore, it can be said that psychological factors do not affect the amount of water consumption for laundry. More than 55% of observed data was distributed under 20 L/p/d, and more than 80% was distributed under 30 L/p/d. This amount was similar to European cities which used drum-type washing machines. Generally speaking, water consumption for semi-automatic washing machines is 1.5 times as much as that for drum-type washers. The reason for less water consumption in Chiang Mai stems from household occupancy. Because the average household occupancy of this survey (4.4) is larger than that of developed countries (between 2.3 and 3.5), clothes washing in Chiang Mai has become so efficient that less water is consumed per capita (Chiang Mai Provincial Statistical Office). Compared with the average water consumption in Bangkok, 45 L/p/d, consumption in Chiang Mai is relatively small. The average household occupancy of surveyed households in Bangkok was 2.37, which is less than that in Chiang Mai (4.4). This is the cause of the difference in water consumption between Bangkok and Chiang Mai. The difference of water resources used, such as public waterworks or non-public waterworks, does not result in the consumption difference as shown from the KS-test.

Similar to water consumption for toilet use, water consumption per capita for laundry use appeared to be distributed through log-normal distribution. R2 values of linear regression are 0.989 for the dry season and 0.983 for the rainy season. This can be verified by the Shapiro-Wilk W-test (significant level >0.05).

3.4 Water consumption for bath water

Because of the hot climate in Thailand, the typical bathroom has a bath basin (Fig. 11). The bath basin is always filled with cold water, and according to the questionnaire survey,

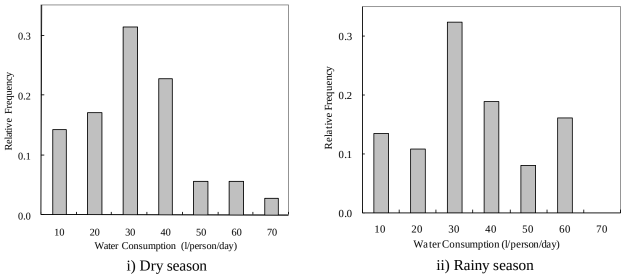

Figure 12. Histogram of consumption per capita for bath.

people bathe themselves in it in order to cool down several times a day. In the bathroom, some households have only a bath basin, whereas others have both a bath basin and a shower, which is used if people want hot water. In this study, 72% of households had both a bath basin and a shower. The water consumption for bath use was expected to depend on the temperature, and not just the season. As temperatures in the dry and rainy season remain almost the same, our supposition was that there would be no significant difference in water consumption.

Figure 12 indicates the histogram of water consumption for bath use in the dry and rainy seasons. According to the KS-test between these two histograms, there is no significant difference (significant level >0.05) between the dry season and the rainy season as we supposed. Most households used 20–30 L/p/d, which was similar to the European cities. People in Singapore, where the climate is similar to Thailand, used much more water (about 80 L/p/d) because they showered several times a day. In Chiang Mai, people also used the bathroom several times a day. However, they did not shower, but used stored water in the bath basin instead. Thus, water consumption did not have a higher level there. Consumption in Chiang Mai was half as much as that consumed in Bangkok (68 L/p/d). Although both climate and culture in Bangkok are the same as those in Chiang Mai, the difference in the progress of its water system construction may have resulted in the difference in consumption. The difference of water resources did not result in the consumption difference, judging from the KS-test.

Similar to water consumption for toilet and laundry use, water consumption per capita for bath water appeared log-normally distributed. The regressions were R2=0.983 for the dry season and R2=0.984 for the rainy season. This was verified by the Shapiro-Wilk W-test (significant level >0.05)

3.5 Water consumption for the kitchen

According to the survey data, in Thailand, there is typically a huge water jar in the kitchen that is used to store water for cooking, and bottled water is used for drinking. Dirty dishes are soaked in the washing-up bowl in the meantime, and then washed later. Figure 13 indicates the histogram of water consumption for kitchen use in both the dry and rainy seasons. According to the KS-test between these two histograms, there is no significant difference (significant level >0.05) between the dry season and the rainy season. 80% of the households used under 30 L/p/d, which is similar to European cities and to Singapore (Otaki, 2003). The average consumption in Bangkok (4 L/p/d) was very small, and was the same as the consumption for dishwashers in US cities (Otaki, 2003). This might be because people in Bangkok usually do not cook at home. On the other hand, 95% of surveyed households in Chiang Mai usually have dinner at home, so consumption in Chiang Mai was larger than that in Bangkok. For the same reasons described above and according to the KS-test, the consumption difference cannot be attributed to the difference of water resources (i.e., public waterworks or non-public waterworks) used.

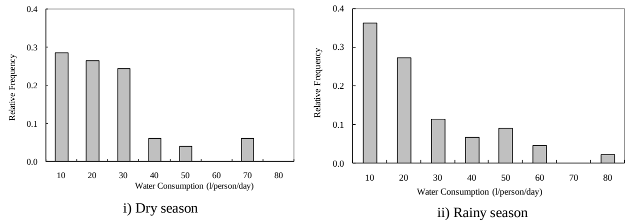

Figure 13. Histogram of consumption per capita for kitchen.

Similar to the water consumption for other uses, the water consumption per capita for the kitchen appears distributed through log-normal distribution. R2 values of linear regression are 0.996 for the dry season and 0.995 for the rainy season. This can be verified by the Shapiro-Wilk W-test (significant level >0.05).

3.6 Future water demand

Based on the measurement results of micro-component use, future water demand was estimated for two scenarios (see Table 3). A water consciousness scenario means that the government and inhabitants willingly try to introduce water-saving appliances, and the usual scenario means that people do not use such appliances.

Currently, pail toilets need about 4 L per use and will be replaced by flush toilets in future. Toilet consumption will surely increase, and the amounts will differ greatly depending on whether water-saving flush toilets (6 L/flush) or usual flush toilets (10 L/flush) are introduced. With respect to clothes-washing, the current popular method is a twin-tub washing machine, the consumption per load being estimated at 100 L. It will be replaced by a fully automatic type. The usual automatic type consumes about 150 L per load. If the water-saving type of automatic washing machine becomes widely used, the amount of water consumption for laundry use will become lower than at present.

Table 3. Water demand estimation (l/p/d).

	Present	Water consciousness scenario	Usual scenario
Toilet	15 (13% flush, 87% pail)	20 (100% flush)	31 (100% flush)
Laundry	18 (mainly twin-tub)	16 (fully automatic)	27 (fully automatic)
Bath	25	75 (Singapore level)	75 (Singapore level)
Kitchen	19	19	19
Total	77	131	152

Bath water consumption will certainly increase in both scenarios. In Singapore, where the climate closely resembles that of Thailand, the average water consumption in bath is 75 L/p/d, which makes up 45% of total indoor water use. There is the possibility that the bath water consumption in Chiang Mai will increase to the Singapore level. Although a low flow shower-head has been developed, it proved ineffective (DeOreo, 2001). Consequently, the estimation of water consumption for bath use is 75 L/p/d for both scenarios.

There are no factors that would increase water use in kitchens in the immediate future. In this study, the median value in dry season was 19 L/p/d. This value is not much different from the value in Singapore, 17 L/p/d. Therefore, we assume the water use in kitchens will not increase in both scenarios.

Total estimation value differs by scenarios. Thus, when planning the future water supply in middle-developed countries, we have to encourage people to install water-saving appliances and devices in conjunction with water planning. It will avoid a waste of time and money, and over-development.

4 Conclusions

It was expected that rainfall differences between the dry and rainy seasons would influence people's awareness of the available water resources so that water consumption in the dry season would be less than that in the rainy season. However, the results proved to be opposite to our expectations. In other words, there was no significant difference in water consumption for all activities between the dry and the rainy seasons. Although some households still used rainfall in Chiang Mai, people did not think of rainfall as a water resource because it was not their main water resource. People did not conserve water because it was the dry season, nor did they waste water during the rainy season.

Furthermore, the differences in water resources such as public waterworks, which can be used easily by just running a faucet, or non-public waterworks like community waterworks, mountainous water and groundwater, did not factor much in the consumption difference.

Water consumption per capita for every usage appeared to be distributed with log-normal distribution, and was verified by the Shapiro-Wilk W-test (significant level >0.05). This tendency was found in previous studies on water consumption, which further supports the reliability of our methodology and collected data.

Important findings from this survey were not only the detailed data of water consumption but also the knowledge of the lifestyle and traditional water use patterns. We also learned that most of the households in the middle-developed country still use old-fashioned appliances, even in the large cities. For example, only 30% of households used flush toilets, the twin-tub washing machine is still popular, and 30% of households did not use showers. Along with the general level of development, new appliances will be introduced and the water demand will certainly increase. At this occasion, the future water demand largely depends on whether water-saving appliances are introduced or not.

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