ISSN 2278-3091
Volume 8, No.1.6, 2019
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse6181.62019.pdf
https://doi.org/10.30534/ijatcse/2019/6181.62019

Pre-Determined Household Routines Parameters Values of Domestic Water Consumption

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ABSTRACT

Domestic water consumption is affected by various factors such as number of households, type of house, and occupation. Moreover, depending on the type of technology used such as water-using appliances and fixtures associated, consumption for a specific household routine can differ greatly. However, in Malaysia, there is a limited study on water consumption patterns by different household routines. In this research, the household routines parameters are identified via various literatures. It is then complimented with the secondary data collection in Seremban, Negeri Sembilan to yield pre-determined values (low, medium, and high) of domestic water consumption parameters. The final values are then determined to produce static pre-determined water consumption values for each parameter. These values allow more insight towards accurately estimating or classifying domestic water consumption.

Key words: Domestic, Household, Water Consumption, Parameters.

1. INTRODUCTION

Human demand for water is predictable to increase as the world population is also predicted to grow to 8.5 billion in 2020 and 9.7 billion in 2050 [1]. Currently, some regions in Malaysia is facing water scarcity problem although Malaysia has high quantity of water resources [2]. As stated in [3], most of domestic water consumer in Malaysia does not practice water saving thus it will lead to water shortages in the future if the Malaysian still practicing the same attitude. Therefore, there is a need to acknowledge that household routine also plays a major role in affecting household water consumption as it is accumulated directly from the household routines.

Furthermore, by recognizing the household water consumption by household routines will help to a more practical and current demand estimations of the domestic sector. Thus, it is vital to understand the drivers of water consumption at a household level and how consumption can be reduced. This research proposes the employment of pre-determined household routines parameters values of domestic water consumption that can be utilized for the purpose of correctly estimating and classifying domestic water consumption. These values are produced by revisiting various literatures to identify the related parameters values and subsequently compliment them with the real values via secondary data gathered from Seremban, Negeri Sembilan.

In the next section, various literature reviews related to parameters influencing water consumption are deliberated and the values of each parameter are extracted.

2. DOMESTIC WATER CONSUMPTION HOUSEHOLD ROUTINES PARAMETERS

Household routine involving water-using appliances includes indoor and outdoor water consumption. According to [4], indoor water consumption consists of hygiene (bathing, laundry and cleaning), drinking as well as cooking, whereas outdoor consumption comprises of car washing, livestock watering and yard cleaning. This section presents a review of household routine involving water-using appliances that will be the crucial micro-components in the research.

2.1 Bath and Shower

Practically, daily household routines in the home bathroom consume the most water in the household. Thus, bath and shower account most of the residential water consumption [5]-[7]. In India, bathing consumes the highest amount of water consumption [8] which accounts for about 55% of residential water consumption [9]. In Malta, it was found that showering makes up 34% (80.4 L per person per day) of residential water consumption [10]. Besides that, Willis et al. [11] agreed that the highest end use of residential water is showering (50 L per person per day) equating to 33% of total consumption.

Furthermore, researchers in [12] identified that showering is the highest residential water consumption in Malaysia which amounted to 124.8 L per person per day, almost as double to

the estimation of 78 L per person per day calculated for Thailand households. In [13], the authors had found from the 1,188 data logged homes, bath and shower make up 18.5% of indoor residential water consumption. The relative efficiency of taking bath and shower is determined by several factors such as the size of the bath tub, showerhead flow and bathing preferences. There is a considerable difference between old and new properties in terms of water consumption through showers [9]. According to [12], the usage of low shower head can save water up to 8194 L. Moreover, [14] presented that low flow showerheads reduce the consumption by 125 gallons on an annual basis. Referring to [15], for showering, an ordinary showerhead consumes 17 L per minute whereas water efficient showerhead only consumes 8 L per minute. In the meantime, a study done in [6] stated that 36 L of water are consumed per shower.

Furthermore, it is also stated for bathing, a full bath tub requires 140 L and half full bath tub using 80 L. Household Guide to Water Efficiency [16] also suggested that a full bath tub requires 150 L of water or more. In addition, [6] proposed 76 L per bath. From the reviews, it can be determined that using water-efficient appliances and fixtures major factor in saving water. In addition, the duration of bath and shower also affects the amount of the water consumption as longer duration tends to use high volume of water. According to Household Guide to Water Efficiency [16], 76 L of water is consumed when using a 9.5 liter-per-minute showerhead for a duration of an eight-minute. As stated by [17], 71.5% of all showers were between four and 10 minutes in length with similar duration during both winter and summer. Meanwhile, from the study conducted by in [14], the households nearly half agreed or strongly agreed that they enjoy regularly taking long showers and baths (44%) and that the quality of the bathing and showering experience is more important than the volume used (41%). In conclusion, bath and showers shown to consume most of water compared to other activities occurred in the bathroom.

2.2 Personal Hygiene

In this research, personal hygiene routines comprised from brushing teeth, washing hand and face. The water consumption for personal hygiene routines is varied as researchers and water companies have different findings for this routine. For instance, NYC Environmental Protection [18] indicated that brushing teeth with the water running consumed about 4 gallons (15.14 L) of water, contrast to [6], brushing teeth with running water consumed only 1.7 L. In addition, International Water Consumption Data Compilation [19] revealed that brushing teeth used a minimum amount of 8 l/p/d to a maximum amount of 40 l/p/d.

Furthermore, in some of the findings, the consumption for brushing teeth and washing hand or washing hand and face are combined as these practices are usually done one after another. According to Howard and Bartram [20], the most critical times of washing hand are following defecation and before eating. Study in [21] suggested that rinsing with 2 L of clean water proved to be protective although this seems to consume a large amount of water. Meanwhile, International Water Consumption Data Compilation [19] categorized washing hand with running water into three ranges: low (2 l/p/d); mid (4 l/p/d); and high (8 l/p/d). Contrary to the study in [21], the amount of 2 L for washing hand is considered as low consumption in the International Water Consumption Data Compilation [19] compilation.

Additionally, [22] estimated brushing teeth and washing hand with a running tap consumed 5 l/p/d. On the other hand, Bari et al. [12] presented brushing teeth and washing hand consumed 31.5 l/p/d for the water consumption patterns in Greater Kuala Lumpur. The consumption is extremely high compared to the [22] estimation. Furthermore, in the study conducted by [23], the basic water requirement for a person to wash hand and face is estimated about 4.1 L. In the meantime, the Austrian households used 9.5 L for personal hygiene [7]. To conclude, activities for personal hygiene varies according to different studies. Therefore, to establish the amount of water consumption for this routine, the activities need to be determined first.

2.3 Flush Toilet

One of the household routines involving water-using appliances is flushing toilets. Reference [24] studied and found that toilet flushing was the largest component which accounted for 26.7% of indoor per capita water use. Water consumption for this activity also differs depending on the types of toilet and the frequency of toilet flushing in a day.
There is a considerable amount of literature on the toilet models stated that each toilet is different, even if they are the same make and model [13]. For instance, old toilets can use up to three times more water than current required fixtures. According to Household Guide to Water Efficiency [16], older toilets probably used between 13 to 20 L of water whereas new toilets consume only 6 L or less. The study also found that single-flush toilets flush the same volume of water every time the flush handle is activated. While for dual-flush toilet models, a larger volume of water to flush solid waste or a smaller volume of water to flush liquid waste.

In addition, [15] stated that single flush toilet consumes 12 L per flush while dual flush toilet consumes 8 L per flush. The International Water Consumption Data Compilation [19] reported that standard sitting flush toilets require minimum of 6 L per flush and maximum of 23 L per flush dissimilar to dual flush toilets that requires 2.3 L per flush for urine and 6 L per flush for faeces. On the contrary, a urine diversion flush toilet (UDT) only consumes 0.3 L per flush for urine and 2.5 L per flush for faeces. Hua [25] in his research also supported that dual flush cistern benefits from lower volume of wastewater and could save 12% of average daily water

consumption. Bari et al. [12] also agreed that the usage of dual flush toilet system can save up a large amount of water up to 3525 L. Reference [14] also addressed low flow toilets reduce the consumption by 363 gallons on an annual basis. Hence, it is evaluated that dual-flush and low flow toilets offer the potential for additional water savings over most single flush models.

In terms of the frequency of toilet flushing, it has been found that the average frequency of toilet flushing is five flushes per day per person [5], [13], [19] whereas [7], [16] indicated that the frequency was estimated to be six flushes per person per day. Additionally, [17] claimed the calculated average toilet flush per capita per day is different during summer and winter. The study pointed out that 4.2 L and 4.4 L of water used for flushing toilets during summer and winter respectively. The number of flushes is found to be 3.7 times per person per day.

Different socio-demographics are also one of the possibilities affecting the consumption of toilet flushing. The amount of water consumption varied significantly across different countries and regions. For instance, Inocencio et al. [23] estimated basic requirement for toilet flushing used 7.9 l/p/d in Philippines. In contrary, the amount of consumption for toilet flushing is higher in other countries such as 29.7 l/p/d in Austria [7], 31 l/p/d in Thailand [17], 37.1 l/p/d in Netherlands [7] and 43.9 l/p/d in Malta [10]. Malaysia unexpectedly recorded almost a double of the average consumption for toilet flushing which are 62.6 l/p/d [12] and 63.3 l/p/d [25]. Hence, the amount is considered in the high consumption range in this research.

2.4 Laundry by Handwashing

Laundry routines can be done using handwashing and washing machine. Laundry by handwashing is the least favorable as it is both time and energy consuming. Also, there is not much studies focused on this routine compared to other household routines in this research. However, few researchers discussed the consumption of laundry by handwashing in their studies. As estimated in [23], the basic requirement for laundry by handwashing is 4.7 L per wash. Meanwhile, Dutch households used about 1.7 L per wash, only one percentage of the overall PCC [7]. In addition, International Water Consumption Data Compilation [19] logged 10 L to 20 L per wash per day for washing clothes by hand. To sum up, the consumption for this routine is low and gives little impact on the total household water consumption.

2.5 Laundry by Washing Machine

Laundry by washing machine was the second largest component of indoor consumption [13]. Water consumption for laundry varies depending on the technology used, types of washing machines (e.g., semi-automatic, fully-automatic, and front or top load) and number of volumes per load [23].

In terms of types of washing machines, there are also significant differences in the amount of water consumption between front and top loaders. Front loader washing machines are more water-efficient as it requires less water per cycle. Several researchers and water authorities identified the average volumes of water used per cycle for front loaders were 60 L [15], 78.5 L [17], 71 L [26] and 15 L to 113 L [27] per cycle. It has also been found that the top loader washing machines consumed 150 L [15], 153 L ([17], 143 L [26] and 151 L [27] per cycle. Besides that, older washing machine models also consumed a large amount of water. Reference [6] found that younger washing machine used 44 L per cycle whereas older washing machine consumed 100 L per cycle.

Moreover, many studies discussed on the average of water consumption for laundry by washing machine per load. The water used for a load were varied from as low as 18.3 [12] to a maximum of 190 L [28]. In the low range consumption, some of the researchers in their studies have analysed the amount used were 22.9 L [7], 22.7 L [29] and 31 L [22] per load. Meanwhile, for the average to high consumption of water were 42.2 L [25], 43.9 L [10], 50 L [19] and 52 L [30] and 150 L [31] per load.

Furthermore, the number of household size also influences the volume of clothes and loads of the washing machine. Other researchers have examined the average total consumption for laundry by washing machine per load per person per day was 0.35 L [5] and 0.28 L [7]. Generally, as the size of the household increases, washing machine is more efficient as the amount of water used for clothes washing per person decreases. However, since the technology is advancing where household can individually customize the washing machine setting, even with a small number of households still can use the washing machine based on the quantity and volume of the clothes. In conclusion, laundry by washing machine is very significant in determining the overall water consumption as this routine consumes a large amount of water although using only a small load per wash.

2.6 Food Preparation

In this research, food preparation is a household routine involving cooking and drinking on a weekly basis. The water consumption for this activity varies depending on the household size and the frequency. Typically, family with a large member prefers to cook at home rather than eating outside due to cost. Moreover, defining the requirements for water for cooking is difficult, as this depends on the diet and the role of water in food preparation [20].

According to [16], kitchen water consumption accounts for about 15% of total indoor water use. While drinking and cooking has the lowest water consumption for Indian residential households, cooking and bathing consumes highest amount of water in New Town [8], [32]. In addition, considering drinking needs, Howard and Bartram [20] suggested between 1.5 and 2 l/p/d is used for drinking. In the literature, the averages of water consumption for food

preparation were mostly between 4 l/p/d to 10 l/p/d [7], [30], [31], [33]-[35]. To summarize, although the water consumption for food preparation is relatively low, it is difficult to be determined since many factors such as different types of foods and number of servings also needs to be considered.

2.7 Water Plant

Water plant is one of the outdoor household routines in the study. There are a few options to water the plants such as using pail, hose or water pipe, watering can and sprinklers. Water consumption differs based on the fixtures and tools used. Reference [17] analyzed households that used hose and manual sprinklers consumed the highest amount of water per garden watering (488 L) due to its long duration (59.1 min) although they only water their garden less than twice per week (1.8 times). Using Water at Home [15] also stated that hand-held hose or sprinkler consumes 18 L per minute of water compared to a bucket or watering can that used about 9 L per bucket. The study conducted by Gato-Trinidad et al. [17] also found that 57% of households used hose as their main method of garden watering, followed by manual sprinklers (23%) and automatic sprinklers and combination of hose and manual sprinklers (20%).

Furthermore, [12], [36] discovered that outdoor uses such as gardening consume minimal water consumption. Greech [10] also presented Maltese households used only 2% (5.1 l/p/d) whereas Ramulongo et al. [8] reported only 6% of water consumption of overall domestic water consumption were used to water plants. To sum up, how the households watering their plants need to be noted as there is a big difference using a bucket and sprinkles in the garden.

2.8 Wash Car

Washing cars is an outdoor household routine that either contribute to small or large water consumption depending on the number of own cars and various ways of washing it. Depending on the device used, trigger nozzle hose consumed 18 L per minute while high pressure cleaning device consumed 6 L per minute. In addition, households that have reported using hoses to wash cars do not have particularly higher outdoor use [14]. According to [10], [36], car washing only make up a small component of water consumption (5.1 l/p/d). Reference [8] studied and showed that the households used about 13.5 l/p/d to wash cars. Previous studies by Zaneti et al. [37] stated that in Queensland, Australia, it is mandatory the use of at most 70 L of fresh water in a single car wash. Meanwhile, in Europe some countries restrict the water consumption to 60-70 L per car. Moreover, in a recent paper by Haida et al. [6], it has been found that the amount of water for washing a car was 100 L. Average Water Use [31] otherwise suggested 200 L was the amount needed to wash a car. In conclusion, cars also vary in terms of size hence the water consumption may differ greatly depending on the car model.

2.9 Miscellaneous

Outdoor household routines comprised of unknown leakage and cleaning (e.g. drains and pavement wash) is considered under miscellaneous routines. Exceptionally high leakage figures are typically found in houses with swimming pools, outdoor water features, hot tubs and irrigation systems [13]. The literature on miscellaneous routines shows a variety of consumption. Several publications indicated that water used for this routine did not exceed more than 50 l/p/d. For instance, the estimated consumption in the low range included 1.4 l/p/d [33], 3.1 l/p/d [23], 3.8 l/p/d [34] and 5 l/p/d [22, 31] Furthermore, several authors also proposed the average amount of between 10 to 15 l/p/d used for miscellaneous routines [7]. In the analysis done by other researchers, slightly higher of water was used for these routines such as 28 l/p/d [15, 30], 31.7 l/p/d [25] and 36 l/p/d [10, 29]. Although the authors did not state precisely the breakdown of water usage for the miscellaneous, most of the authors agreed that miscellaneous activities were categorised under outdoor household routines.

3. METHODOLOGY

For this research, household routines that involve water-using appliances are being selected as the parameters. The parameters are separated into two categories: daily and weekly routines. Daily routines are the routines that are done daily by one person. Daily routines are indoor routines that is done daily by a single person and commonly occurred in the bathroom to fulfil one's basic needs on sanitation and hygiene. In this research, daily routines are made up of bath and shower, flush toilets and personal hygiene (brush teeth, wash hand and face).

In the meantime, weekly routines are routines that are done by the entire households each week. The routines are considered as weekly due to the routines may not necessarily happens often and the households have other alternatives of doing it such as eat outside, doing laundry at dobby or wash car in the car wash. For the purpose of this research, weekly routines consist of cooking, laundry (hand and washing machine), water plant, wash car and other miscellaneous routines (e.g. ablution). Each household routine parameters and the water consumption value has been discussed in detailed in earlier section.

3.1 Data Collection

This research used a secondary data collected by a group of students (Bachelor of Science (Hons) Statistics) in Universiti Teknologi Mara (UiTM) Seremban. This data has been used in the study by [38] to detect excessive residential water consumption and to predict domestic water leakage based on consumer water consumption data [39]. Table 1 illustrates the household routines parameter and identifier collected from the secondary data.

Table 1: Household Routines Parameter and Identifier

Household Routines	Parameter	Identifier
Bath/Shower	Bath/Shower	$p1$
Brushing Teeth/Washing Hands/Face	Personal Hygiene	$p2$
Flushing Toilet	Flush Toilet	$p3$
Washing Clothes by Hand	Laundry - Handwashing (*per load*)	$p4$
Washing Clothes by Washing Machine	Laundry - Washing Machine (*per load*)	$p5$
Cooking	Food Preparation	$p6$
Watering Plant	Water Plant	$p7$
Wash Car	Wash Car	$p8$
Other	Miscellaneous	$p9$

The data was collected using a questionnaire survey carried out randomly in an urban area in Seremban to 80 households with a total of 367 occupants. There was no specific residential area stated in the data sets. The type of residential households in this sample consists of single storey terrace and double storey terrace. In addition, the age of the residential households is between one year old to 44 years old. Among 80 households, there are 27 households with children and 53 households without children.

3.2 Experimental Design

Initial studies on the literatures carried out in the research methodology framework inferred the most influential household routines towards the household water consumption. This experiment is done to verify and recognize the household routine parameters that have high-influenced on the monthly household water consumption or the 80 households. Table 2 tabulates the experimental design of verifying high-influenced household routine parameters.

Table 2: Experimental Design of Verifying High-Influenced Household Routine Parameters

Experimental Design of Verifying High-Influenced Household Routine Parameters	Constant Value
Number of Households	80
Household Routine Parameters	Bath and Shower Flush Toilet Personal Hygiene Laundry by Handwashing Laundry by Washing Machine Food Preparation Water Plant Wash Car Miscellaneous
Pre-determined Water Consumption Volumes	Low Medium High

The values obtained from the literature are then tested to estimate the monthly water consumption for each household via the following equations (1), (2) and (3).

$$e = d + w \tag{1}$$

$$d = \sum_{n=1}^{3} (sp_n a_n)(30)(c_n) \tag{2}$$

$$w = \sum_{n=4}^{9} (p_n a_n)(\frac{30}{7})(c_n) \tag{3}$$

The estimated monthly household water consumption (e) is the addition of daily (d) in (2) and weekly (w) in (3) consumption. Based on the equations in (2) and (3), n refers to household routines parameters identifiers earlier, s is household size, pn is frequency of household routine parameters, an is pre-determined water consumption values, cn is coefficient of micro-component water consumption values, which by default is set as 1 in current implementation.

4. RESULTS AND DISCUSSION

To produce pre-determined water consumption values range for the sample, literature reviews on water consumption of the household routines involving water-using appliances is explored and revised. A review of the literature on this matter taken the detailed analysis of data from the previous section into consideration. For instance, one of the criteria needed in finding the household routines' water consumption is to look for the cities or countries that has per capita consumption similar to the PCC of Malaysia (211 l/p/d) and Seremban (234 l/p/d).

In addition, the amount of water consumption for the household routines from the countries with the same climate and weather as Malaysia was also noted. This is to ensure that there is not much gap between the usage as other factor also contribute to the usage of water consumption. Once the water consumption is summarized, final adjustments are being made to satisfy each volume of pre-determined water consumption values where a study on water consumption patterns in Kuala Lumpur, Malaysia [12] is set as the main basis so that the values does not stray too far from the Malaysia domestic water consumption figures. Table 3 demonstrates the pre-determined water consumption values parameter for household routines.

Table 3: Pre-Determined Water Consumption Values Parameter (Household Routines)

Pre-Determined Water Consumption Values Parameter (Household Routines)	Id	Low	Med	High
Shower/Bath	$p1$	45	90	180
Personal Hygiene	$p2$	4	12	20
Flush Toilet	$p3$	10	30	60
Laundry - Handwashing (*per load*)	$p4$	5	10	15
Laundry - Washing Machine (*per load*)	$p5$	20	50	150
Food Preparation	$p6$	4	10	15
Water Plant	$p7$	5	20	30
Wash Car	$p8$	20	100	200
Miscellaneous	$p9$	10	30	50

Referring to the Table 3, the pre-determined water consumption values are divided into three volumes: low; medium and high. Low volume is the minimum and basic requirement of the water consumption of the household routines whereas medium volume is the average and common consumption, high volume is the most likely high of water consumption of the household routines. The measurement approach on producing the pre-determined water consumption values has only examined based on the previous analysis highlighted earlier, therefore the pre-determined water consumption values in this research might not be the representative for the actual household routines' consumption.

Despite this, the pre-determined water consumption values can be use as basis or a starting point in defining and estimate consumption for the household routines. The data depended on information being either available in the journal article or being provided by the water companies or organizations. However, there was not enough detail on some of the specific household routines such as laundry by handwashing, wash car and miscellaneous. This affected the extent to which the figures could be analyzed.

5. CONCLUSION

This research provides an insight towards domestic water consumption values specifically in Malaysia. These pre-determined water consumption values, when complimented with the optimized co-efficient values will be able to produce an accurate estimation and classification to domestic household water consumption. However, the optimization could use implementation of optimization algorithm such as genetic algorithm [40], [41] as randomly generating the suitable co-efficient values to compliment these pre-determined water consumption values would require exhaustive and inefficient computing resources.

ACKNOWLEDGMENT

This research is supported by Universiti Teknologi MARA.

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