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Characteristics of domestic wastewater and estimation of required johkasou capacity for buildings in Japan

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Abstract

Quantity and quality of raw domestic wastewater are reviewed and discussed for packaged plants, known as johkasou, in Japan. A method for the estimation of johkasou capacity in terms of population equivalent, or PE, was introduced and discussed in this paper. It was found that the pollutant loads of domestic wastewater were respectively BOD 45 g, COD_{Mn} 23 g, SS 37 g, TN 9.3 g and TP 1.1 g per capita per day on average. It shows that the BOD load of wastewater from kitchens is higher than that of black water. The estimation of the johkasou capacity needed for buildings can be done using a series of formulas, which forms an important estimation method for the implementation of on-site wastewater treatment.

Key words: domestic wastewater, johkasou, wastewater characteristics, unit loading

INTRODUCTION

The quantity and quality of raw domestic wastewater are essential for the design, operation and maintenance of wastewater treatment plants. In the case of small wastewater treatment plants for decentralized sanitation or the so-called packaged plants, they are designed and tested under the condition of a designated quantity and pollutant loads from raw domestic wastewater in most developed countries. To ensure that a packaged plant functions well as designed, the installation of a plant with sufficient capacity for the target house/building is necessary. In many cases, the quantity and pollutant loads of a new building need to be estimated to determine a packaged plant with appropriate capacity. It is important to identify the quantity and quality of the raw domestic wastewater of houses and buildings with different uses.

In Japan, there are three major systems for domestic wastewater treatment, which can be classified into 'sewerage system', 'johkasou system' and 'rural sewerage system'. Johkasou, a type of packaged plant, has been introduced and developed originally to meet the needs of the flush toilets of individual households in the suburban and rural areas in the early 1960s.

Johkasou in general are prefabricated products installed in the yard of houses, which treat domestic wastewater up to a high level of water quality (Figure 1). Different from septic tanks, johkasou are small-scale wastewater treatment plants with a very small capacity, directly discharging the effluent into the surrounding water bodies, instead of infiltrating wastewater into the ground. To ensure normal treatment performance, johkasou are appropriately designed, tested, installed and maintained by certified technicians of johkasou businesses following various technical and administrative regulations. However, the treatment performance of johkasou may become unsteady when the pollutant loads of raw domestic wastewater are beyond the johkasou capacity of treatment. Therefore, it is important to identify the quantity and quality of wastewater and select a johkasou with appropriate capacity in accordance with the pollutant loads it receives.

In this paper, the quantity and quality of domestic wastewater and a method for the estimation of the population for johkasou from buildings for decentralized treatment were reviewed and discussed.

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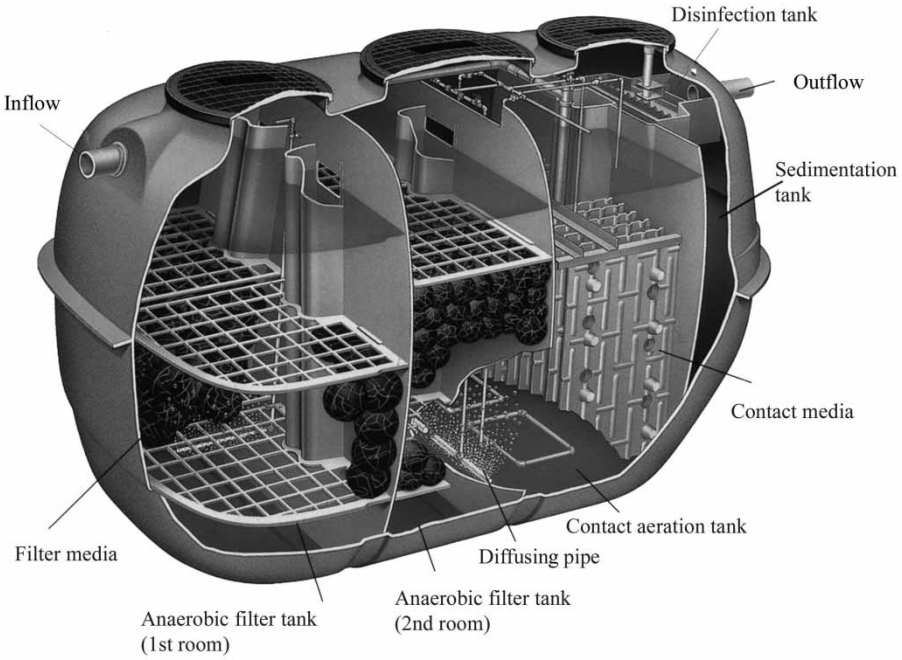

Figure 1 | Schematics of household johkasou.

MATERIALS AND METHODS

Methods of sampling and analyzing

Most of the data on quantity and quality of raw domestic wastewater used in this paper are obtained by on-site sampling from individual houses.

The normal procedures of sampling could be described as follows: (1) Collect every hour all of the discharged raw wastewater from the house, take two liters of raw wastewater as a sample, measure and record the amount of the raw wastewater discharged; (2) take samples in the same way for 24 hours; (3) make composite samples according to the amount of raw wastewater discharged hourly; and (4) perform water quality analyses of the composite samples.

Analysis methods

The composite samples were analyzed using an analysis method for wastewater stipulated by the Japanese Industrial Standards (JIS K 0102). The samples were analyzed to measure the concentrations of biological oxygen demand (BOD), chemical oxygen demand (COD_{Mn}), suspended solids (SS), total nitrogen (TN), total phosphorus (TP) and other items. The pollutant load of each item was obtained by multiplying its concentration with the amount of wastewater.

RESULTS AND DISCUSSION

Quantity of water and wastewater

As the quantity of wastewater discharged basically depends on tap water consumption, it is important to identify the consumption of tap water in houses. A survey (Horio 2001) was carried out on the consumption of tap water over a period of 24 hours for 10 families. The survey results are shown in Figure 2.

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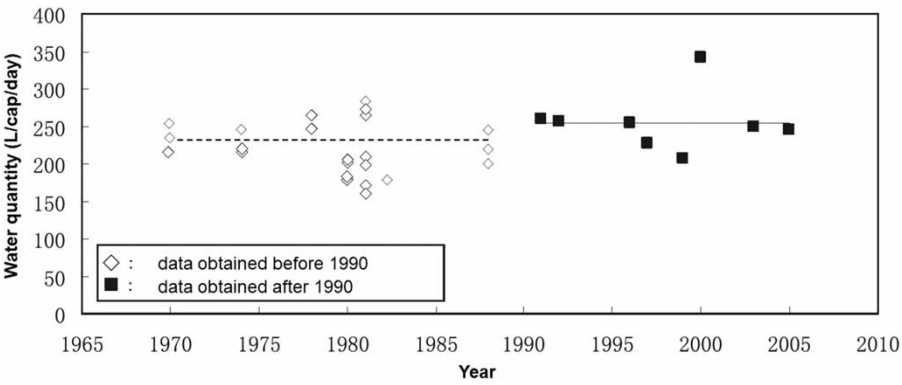

Figure 2 | Water quantity used from different family sizes.

The water quantity was found to vary from 113 to 333 L/cap.day, while the average was 245 L/cap.day. Although the family size of each house is quite different, there seems to be little correlation between the water quantity and the family size.

The data of surveys (Kawamura 2013) on the tap water consumption of houses, which have been carried out every five years by the Tokyo Metropolitan authority over a period of 20 years, show that tap water consumption rates were 220 L/cap.day in 1987, 246 L/cap.day in 1992, 248 L/cap.day in 1997, 244 L/cap.day in 2002 and 239 L/cap.day in 2007, respectively. The fluctuations of the tap water consumption rate varies across a small range, and could be attributed to changes of lifestyle, such as the popularization of new appliances and water-saving trends in recent decades.

A comparison (Kawamura 1995) of wastewater quantity was made and is shown in Figure 3. The data obtained before 1990 show an average of 230 L/cap.day, while after 1990 a rate of 255 L/cap.day is seen. Some other surveys (Fujimura 2006) done in the 1970s and 1980s show that wastewater quantity averaged 229 L/cap.day during that period. These results show that the amount of wastewater discharged from houses increased slowly and varied across a very small range.

The detail of wastewater quantity at generation source is summarized and shown in Table 1 (Kawamura 2013). The wastewater quantity varies from 244 to 265 L/cap.day. The wastewater discharged from flush toilets varies from 36 to 68 L/cap.day, 19–28% of the total amount. Among the generation sources outside flush toilets, the largest proportion of wastewater comes from bathing, accounting for 24–35%, and is then followed by laundry for 17–33%, cooking for 10–23%, and other activities for 3–8%.

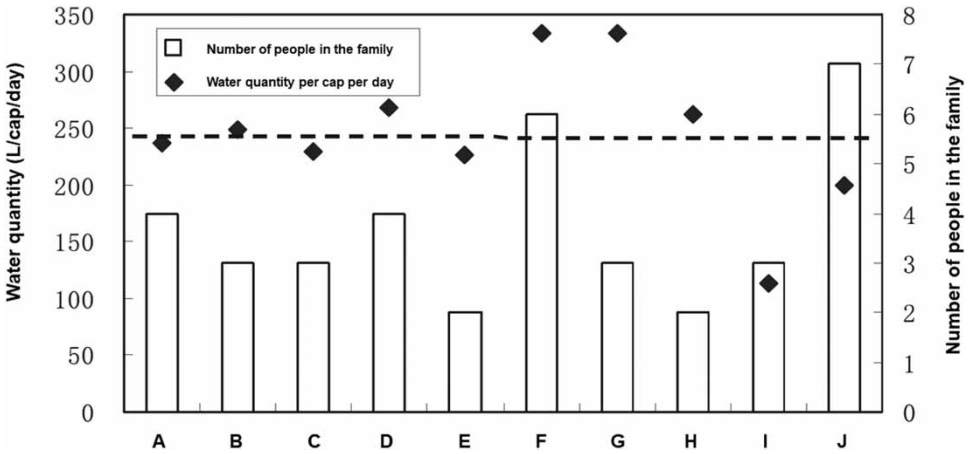

Figure 3 | Water quantity obtained in different periods.

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Table 1 | Quantity of domestic wastewater L/cap.day

Generation source	Ogawa & Tadokoro (2001) %	Ogawa & Tadokoro (2001) L	Kawamura (1995) L	Tokyo Metropolitan Government Bureau of Waterworks (1997) %	Tokyo Metropolitan Government Bureau of Waterworks (1997) L	Tokyo Metropolitan Government Bureau of Waterworks (2002) %	Tokyo Metropolitan Government Bureau of Waterworks (2002) L
Flush toilets	19	50	36–46	24	59	28	68
Cooking	10	27	43–55	22	55	23	56
Laundry	33	87	50–64	20	50	17	41
Bathing	35	92	48–62	26	64	24	59
Others	3	8.5	7–17	8	20	8	20
Total	100	265		100	248	100	244

Pollutant loads

The pollutant loads of domestic wastewater obtained in previous studies (Imura 1994; Inamori *et al.* 1998; Ogawa & Tadokoro 2001; Ishihara *et al.* 2006), which were carried out from the 1970s to the 2000s, are summarized in Tables 2 and 3.

Table 2 | Pollutant loads of domestic wastewater g/cap.day

	Fujimura (2006)		Inamori *et al.* (1998)	Kawamura (1995)	Ogawa & Tadokoro (2001)	Ishihara *et al.* (2006)	Inamori *et al.* (2006)	Imura (1994)	MOE (2006)	MOE (2006)	Avg.
BOD	45	43	47	47	46	36.6	58	50	32.5	41.4	**45**
COD_{Mn}	23	24	27	22	–	12.2	27	25	–	–	**23**
SS	–	–	47	35	–	22.7	45		–	–	**37**
TN	8.1	8.6	12.5	8.5	6.6	–	11	10	–	–	**9.3**
TP	0.9	1.2	1.8	1.0	0.8	–	1.3	1.0	–	–	**1.1**

Table 3 | Pollutant loads of domestic wastewater at generation sources g/cap.day

Generation source	Fujimura (2006) BOD	Fujimura (2006) COD_{Mn}	Fujimura (2006) T-N	Fujimura (2006) T-P	Kawamura (1995) BOD	Kawamura (1995) T-N	MOE (2006) T-P	MOE (2006) BOD	MOE (2006) BOD
Flush toilets	16.0	10.0	7.0	0.70					
Cooking					25.4	0.80	0.100	16.8	21.0
Laundry					5.0	0.20	0.010	3.9	4.0
Bathing					2.9	0.35	0.029	9.1	1.5
Others					0.8	0.32	0.069	0.7	0.5
Total	16.0	10.0	7.0	0.7	34.1	1.7	0.208	30.5	27.0

The pollutant loads of domestic wastewater in terms of BOD vary from 32.5 g to 58 g while the average is 45 g/cap.day. The averages of COD_{Mn}, SS, TN and TP are 23 g, 37 g, 9.3 g and 1.1 g per capita per day, respectively, as shown in Table 2.

The pollutant loads of raw domestic wastewater in other countries have been reported by Henze & Ledin (2001). It was found that the BOD loads were estimated to be 82–96 g/cap.day in the USA, 55–82 g/cap.day in Denmark, Italy and Sweden, 55–68 g/cap.day in Brazil, and 27–41 g/cap.day in Egypt and Turkey; while the TN loads were 13.6–19.2 g/cap.day in the USA and 8.2–16.4 g/cap.day in other countries. It seems that the BOD loads of the raw domestic wastewater

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in Japan are inferior to those of European countries, Brazil and the USA, but are higher than those of Egypt and Turkey. The difference in the figures may partly be due to the different diets and lifestyle between the countries.

The pollutant loads generated at sources are shown in Table 3. It was found that most of the BOD loads come from cooking and black water, which account for more than 70–88% of the total. It also shows that the BOD loads of wastewater from kitchen are higher than that of black water. As for the pollutant loads of nitrogen and phosphorus, black water contains 80% of the nitrogen load and 77% of the phosphorus load. The BOD loads of gray water range from 30.5 to 34.1 g/cap.day, thus being much higher than that of black water. It is therefore important to treat both black and gray water to prevent water pollution in public waters.

Wastewater with high pollutant loads

Food waste disposers (hereafter, 'FWD') have recently spread in urban areas of Japan. Wastewater from FWDs should be treated individually by a treatment plant to a level acceptable by regulations. A new type of johkasou capable of treating both normal domestic wastewater and FWD wastewater has been developed. In this case, it is important to design a johkasou capable of treating the amount and pollutant loads of FWD wastewater.

Some results on pollutant loads due to FWD use are shown in Table 4. The pollutant loads of FWD were found to be 3.7 L for water quantity, 16–24 g for BOD, 5–19.7 g for COD_{Mn}, 7–16.1 g for SS, 0.5–2.1 g for nitrogen and 0.1–0.3 g for phosphorus per capita per day, which were measured through field researches.

Table 4 | Quantity and quality of FWD wastewater g/cap.day

	Water Quant.	BOD	COD_{Mn}	SS	T-N	T-P
Survey 1	3.7 L	16.0	14.0	14.0	0.7	0.10
Survey 2		17.3	19.7	16.1	0.9	–
Survey 3		16–24	5–9	7–15	0.5–2.1	0.1–0.3
Standard method	5 L	25	–	25	1.0	0.25

Pollutant loads by the standard method are obtained by grinding 250 g of standard food waste with 5 L of water by a FWD. For johkasou the pollutant loads are adopted as nominal loads. However, the nominal BOD and SS loads are much higher than those obtained in the surveys.

ESTIMATION OF POPULATION FOR JOHKASOU OF BUILDINGS

General

When a new building is planned and a johkasou is required to be constructed for treating the domestic water that will be discharged by the building, a johkasou with appropriate capacity must be selected according to the uses and the characteristics of the building, using a Japanese standard called 'JIS A 3302:2000 Estimation of Population for Johkasou of Buildings'.

This standard specifies the methods for determining the capacity of johkasou in terms of 'population equivalent' (hereafter, 'PE'), for buildings of different uses. The term PE used in this standard means that the amount of wastewater and pollutant loads for a building are expressed in a unit of PE. In the case of living accommodations, one PE, as shown in Table 5, is equal to

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Table 5 | Building uses defined in JIS A 3302:2000 (partly) and unit loading for buildings

Category	per PE	
	W.Q. (L)	BOD (g)
I Public facility		
Public meeting places, theaters, cinemas	200	30
Horse/Bicycle/Motorboat Racetrack	150	40
Gymnasiums, sports stadiums	155	40
II Living accommodation		
Individual house	200	40
Residential complexes	200	40
Lodging houses and dormitory	200	28
School dormitory houses, nursery homes,	200	40
III Accommodation facility		
Hotels with wedding halls	200	40
without wedding halls	400	40
Motels	200	30
Hostels	200	40
IV Medical facility		
Hospital with kitchens and/or laundry services	125	40
less than 300 beds	125	40
more than 300 beds	113	36
without kitchens and/or laundry services		
less than 300 beds	200	30
more than 300 beds	182	27
Small hospitals	130	40
V Shops, stores		
Stores, supermarkets	200	30
Departmental stores	200	30
Restaurants		
normal pollutant loads	180	40
high pollutant loads	90	40
low pollutant loads	200	40
Coffee/tea houses	200	30
VI Amusement facility		
Disco houses	200	30
Bowling houses	200	30
Amusement parks	150	40
Camp sites	125	40
Golf courses	250	26
VII Parking facility		
Expressway rest areas	135	40
Parking facility	200	40
Gas station	200	40
VIII Schools		
Preschools, elementary schools, junior high schools	200	36
High schools, universities, colleges	200	36
Libraries	200	30

(*Continued.*)

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Table 5 | Continued

Category	per PE	
	W.Q. (L)	BOD (g)
IV Offices		
Offices with kitchen equipment	200	40
without kitchen equipment	270	40
Workplaces		
Factories, institutes, laboratories		
with kitchen equipment	133	30
without kitchen equipment	200	40
XI Others		
Markets	200	40
Public bathhouses	200	10
Public toilet facility	200	40
Stations, bus terminals	200	40

200 L/cap.day of wastewater and 40 g/cap.day of BOD loads discharged from the building. In other words, this is a kind of equivalent way of calculating pollutant loads for buildings of different uses and applying them, such as for those in residential areas. In most cases, the number of PE is not the occupancy load limit or the number of users of a building. Furthermore, in the cases of buildings for commercial uses, it is recommended that the values adopted for the water quantity and BOD load per PE differ from that of living accommodations. Data of unit loading per PE for buildings of different uses are shown in Table 5.

In Japan, the johkasou capacity is usually expressed in terms of PE, and the treatment processes of johkasou, including their unit processes, are stipulated in accordance with the number of PE by the Structural Standard for Johkasou. For example, the biofilm processes are very popular in small to medium scale johkasou for 200 PE or less, while activated sludge processes are popular in medium to large scale johkasou for 201 PE or more.

Furthermore, as the treatment processes are different depending on the johkasou capacity, the content and frequency of johkasou inspection will also be different depending on the number of PE. For example, the frequency of regular inspection has, by regulation, to be conducted three times per year for johkasou with biofilm process for 20 PE or less, while four inspections per year are required for a johkasou for 21–50 PE.

The estimation of johkasou capacity in terms of PE is essential not only for planning and construction/installation, but also for operation and maintenance. A sound method for estimating the johkasou capacity as well as its operational procedures is necessary for promoting decentralized domestic wastewater treatment.

Building uses

There are 11 categories of building uses defined in the standard, as shown in Table 5, and each category contains one or more subcategories.

In the standard, a series of formulas is provided for determining the number of PE of buildings with different uses. Each formula corresponds directly to one building use that is defined in the standard.

For buildings with uses not listed in Table 5, the number of PE could be determined using the formula for buildings with similar uses.

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For buildings with multipurpose uses, the number of PE must be determined by summing up the number of PE obtained with the formula for each building use.

For a johkasou serving two or more buildings, the number of PE must be determined by summing up the number of PE obtained for each building.

Unit loadings

The unit loadings for johkasou of different building uses are shown in Table 5. The wastewater amount and BOD loads shown in the table are recommended to be applied for the determination of a johkasou capacity. If the unit loading in the table is considered unreasonable, the unit loading for similar building use could be adopted.

There are cases in which there is no recommended unit loading. In such cases, the unit loading for similar building use can be adopted.

Besides BOD load, nitrogen and phosphorus unit loadings are recommended for living accommodations, which is 10 g for total nitrogen and 1.0 g for total phosphorus per capita per day.

Examples of estimating PE for different building uses

Living accommodations

The capacity of johkasou for residential buildings is basically determined by the total floor areas, as shown in Table 6.

Table 6 | Determination of PE for living accommodation

Cat.	Building use		PE	
			Formula	Remarks
II	Living accommodation	Individual house	$n = 5$ A < 130	n: PE
			$n = 7$ A $\geqq 130$	A: total floor area (m^2)
		Residential complexes	$n = 0.05$A	P: occupancy load limit
		Lodging houses and dormitory	$n = 0.07$A	
		School dormitory, nursery homes	$n =$ P	

In the case of individual houses, if the floor area is less than 130 m^2, a 5PE johkasou is needed; if not, a 7PE johkasou will be required. For such reasons, the smallest johkasou is for 5PE, which has capacity of treating wastewater of 1.0 m^3/day and 200 g-BOD/day. For a double house or a house with two kitchens, by regulation, a 10PE johkasou must be installed.

Shops and stores

The capacity of johkasou for shops and stores is determined by the total floor areas of the building, as shown in Table 7.

As wastewater discharged from shops and stores may contain oil and grease in high concentrations, a grease interceptor is required to be installed in front of a johkasou. The formulas in category V are designed for shops and stores with normal business hours, basically 8 to 10 hours per day. For the cases of those with long business hours, such as Japanese convenience stores which are open for 24 hours, the capacity of johkasou should be enhanced. For example, if a 10PE johkasou is required by the formula, it is recommended to install a 14PE johkasou for a convenience store.

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Table 7 | Determination of PE for shops and stores

Cat.	Building use		PE Formula	Remarks
V	Shops, stores	Stores, supermarkets	$n = 0.075A$	n: PE
		Department stores	$n = 0.15A$	A: total floor area (m^2)
		Restaurants		
		normal pollutant loads	$n = 0.72A$	
		high pollutant loads	$n = 2.94A$	
		low pollutant loads	$n = 0.55A$	
		Coffee/tea houses	$n = 0.80A$	

Schools, offices and others

The capacity of johkasou for various schools is determined by the occupancy load limit of a school, as shown in Table 8. For high schools and universities with evening class, the occupancy load limit of evening class counts for one fourth of it when calculating the number of PE. If school canteens are available, the number of PE for school canteens should be calculated as restaurants of category V and added to the number of PE obtained by the formulas of category VIII.

An office building with kitchen equipment means that company cafeterias and/or restaurants can offer food service during business hours. The capacity of johkasou for such buildings needs to be 25% higher than those without kitchen equipment.

Table 8 | Determination of PE for schools, offices and others

Cat.	Building use		PE Formula	Remarks
VIII	Schools	Preschools, elementary schools, junior high schools	$n = 0.20P$	n: PE
		High schools, colleges, universities	$n = 0.25P$	P: occupancy load limit
		Libraries	$n = 0.08A$	A: total floor area (m^2)
IX	Offices	Offices		C: number of toilet bowls
		with kitchen equipment	$n = 0.075A$	
		without kitchen equipment	$n = 0.06A$	
XI	Others	Public toilet facility	$n = 16C$	

CONCLUSION

The quantity and quality of raw domestic wastewater were reviewed, and methods for the estimation of johkasou capacity for buildings were explained. The following conclusions were drawn:

- The quantity of domestic wastewater was found to vary from 244 L to 265 L per capita per day according to the results of researches.
- The pollutant loads of domestic wastewater were found to be BOD 45 g, COD_{Mn} 23 g, SS 37 g, TN 9.3 g and T-P 1.1 g per capita per day on average. It shows that the BOD load of wastewater from kitchen is higher than that of black water.
- The pollutant loads of FWD wastewater were found to be 3.7 L for water quantity, 16–24 g for BOD, 5–19.7 g for COD_{Mn}, 7–16.1 g for SS, 0.5–2.1 g for TN and 0.1–0.3 g for TP per capita per day.
- The unit loadings for johkasou design in the case of living accommodations are 200 L of wastewater BOD 40 g, TN 10 g and TP 1.0 g per capita per day.

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- The unit loadings (water quantity and BOD load) for the johkasou of buildings for different uses are provided informatively.
- The johkasou capacity in terms of PE can be estimated by a series of formulas provided by a standard. The method of estimating the number of PE is very important for the implementation of on-site wastewater treatment by packaged plants.
- Examples of estimating the number of PE for different building uses were conducted. It implies that there are special cases that should be considered when determining the number of PE by the formulas.

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