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Article

Evaluating Performance Testing for Fabricated Wastewater Treatment Plant in Indonesia

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Abstract: The push towards achieving 100% access to wastewater services in Indonesia necessitates the development of cost-effective non-sewer systems. Decentralized wastewater treatment systems, such as septic tanks, are prevalent but often fail to meet effluent quality standards. This study aims to evaluate the performance of various Fabricated Wastewater Treatment Plants (F-WWTP) with test methods adopted from Japanese test methods and adapted to conditions in Indonesia to determine processing unit standards to meet domestic waste quality standards set by the Ministry of the Environment and Forestry. The study was conducted in two stages: opinion polls through stakeholder meetings and performance testing of three small-scale F-WWTPs in Bandung, Indonesia. Stakeholders included various governmental and research institutions. The F-WWTP tested included configurations of anaerobic, anaerobic-aerobic, and anaerobic-anoxic biofilter systems. The performance evaluation was based on physical, chemical, and biological parameters, such as COD, BOD, TSS, and ammonia concentrations, monitored over 12 weeks. Effluent quality varied among the F-WWTPs, with COD concentrations ranging from 25.70 to 215.0 mg/L, BOD from 7.02 to 133.3 mg/L, TSS from 2.98 to 38.70 mg/L, and ammonia from 1.76 to 52.80 mg/L. Statistical analysis using one-way ANOVA showed no significant difference in pollutant removal efficiency among the F-WWTPs. The average BOD/COD ratio indicated moderate biodegradability, aligning with findings from other studies. When properly configured and maintained, decentralized wastewater treatment systems can achieve the effluent standards Indonesian regulations require. This study highlights the necessity for reliable performance testing and certification to ensure the quality of decentralized systems, preventing market entry of substandard products. Future research should focus on long-term field performance and developing more efficient treatment configurations.

Keywords: decentralized; domestic wastewater; F-WWTP; septic tank; testing performance

1. Introduction

In pursuit of access to wastewater services to reach the target of 100%, it is undeniable that the non-sewer system, sometimes called decentralization, should continue to be developed. This must be done because non-sewer systems do not require large costs compared to centralized systems. In addition, the application in the field can be carried out in a shorter time than the centralized system. According to the

Ministry of Public Works and Public Housing's 2022 Performance Report, around 63% of domestic wastewater in Indonesia is still not treated adequately or at all before being discharged into the environment. Most home garbage is discharged directly into rivers, lakes, or seas without proper treatment.

It is a common practice that landed houses, self-built or provided by the real estate sector, are equipped with septic tanks. 'A city with millions of septic tanks,' an official at the Ministry of Public Works described Jakarta's sanitation condition. Up to 2005, it was estimated that in the city, 1.6 million septic tanks were serving individual houses (Miller, 2006). A septic tank is usually used to recover black water containing human excreta. Meanwhile, grey water from washing and bathing remains untreated before being charged into the ground and water bodies. In many cases, the operation of a septic tank is the individual owner's responsibility. The septic tanks have no quality control, allowing leaking ones to be kept in place (Putri, 2017).

Various manufactured septic tank products have been produced to target individual services expected to comply with SNI (Indonesian National Standards) standards for septic tanks (SNI-2398-2017). Without modification, the form of a septic tank is still insufficient if the effluent is discharged into the channel or surrounding water bodies because it still does not meet quality standards. Therefore, a field of infiltration or further processing with a small-bore sewer system must be channeled to a communal WWTP (Wastewater Treatment Plant) for a limited area or residential area. Apart from that, the fecal sludge accumulated in the septic tank is still necessary for desludging within 2–3 years to be processed in the fecal sludge treatment plant.

With technological advances, septic tank modification systems have been developed to meet the effluent quality standards for domestic waste, as issued by the Ministry of Environment and Forestry No. 68 of 2016. The septic tank modification systems developed in the market vary widely, namely biological processes in anaerobic and aerobic conditions, biological, physical, and chemical combinations, and so on. This research aims to evaluate the performance of a Fabricated–Wastewater treatment plant (F-WWTP) in processing domestic waste. The performance of the F-WWTP that will be tested has different configurations, so the results of this research are expected to compare the processing efficiency carried out on each F-WWTP. In this way, the performance testing standard unit could be developed in Indonesia.

Why do we need a standard for performance testing methods?

Various prefabrications of WWTP products are circulating on the Indonesian market without guaranteeing they can be processed according to applicable quality standards. The unavailability of these regulations has the potential to circulate poor-quality products, as is the case in most developing countries, such as Indonesia, Vietnam, Myanmar, and others.

Many decentralized Wastewater Treatment Plants (WWTP) applications have low performance, and the effluent does not meet standard effluent. To ensure compliance with the regulation, it is necessary to develop a performance testing scheme for decentralized domestic wastewater treatment plants (Darwati and Hastuti, 2019). However, it's easy to profit if they produce poor performance and/or weak tanks. To eliminate low-quality treatment facilities from the market. Performance testing methods and reliable certification systems are required, as well as low capacity of technical design and application by manufacture.

If the septic tank only consists of one compartment, then only part of the solid particles will be removed around 30 (%). Meanwhile, there is only 31.5% removal as BOD and COD for organic, so the liquid that comes out still requires further processing (Lesmana, 2019). If directly discharged into drainage channels, as is generally the case in Indonesia, it will potentially pollute water bodies. Apart from that, desludging the feces is still necessary for a period of 2–3 years.

Effluent Standard for Domestic Wastewater

Table 1 shows the effluent standard for domestic wastewater in Indonesia, both by province and national standards. A province that does not have the effluent standard will use the national standard. Standards appear at the provincial level due to environmental problems on a local scale. In general, the highest quality standard that applies is the national standard.

Prefabrication of WWTP

With the advancement of technology, various septic tank modifications have been produced. However, according to the Indonesian Ministry of Environment and Forestry, not all have fulfilled the applicable effluent quality standards. Among the modifications made were anaerobic and aerobic conditions, meaning that additional energy is needed to meet these aerobic conditions. Technology development also needs to be considered to remove nitrogen and phosphate groups, for example, by adding processing units or modification by recirculating.

Testing the performance of wastewater treatment in the laboratory and field is intended to determine the efficiency of removing contaminants according to effluent standards. In Japan, newly developed on-site domestic wastewater treatment facilities need to be tested for a minimum of 48 weeks outside or a minimum of 16 weeks with temperature variations in a laboratory.

Table 1. Effluent Standard of Domestic Wastewater in Indonesia.

Parameter	Province					National Standard	
	Jakarta No.122/2005	**Middle Java No.5/2012**	**Yogjakarta No.7/2016**	**East Java N0.72/2013**	**South Sulawesi No.69/2013**	**No.5/2014**	**No. 68/2016**
pH	6–9	6–9	6–9	6–9	6–9	6–9	6–9
TSS (mg/L)	50	100	75	50	100	100	30
BOD_5 (mg/L)	50	100	75	30	75		30
COD (mg/L)	80		200	50	100	100	100
Oil Grease (mg/L)	10	10	10	10	5	10	5
Ammonia (mg/L)	10				5		10
Detergent (mg/L)	2		5		1		
Coliform (MPN/100 mL)			10,000				3,000

In general, manufactured WWTPs use a processing process with a biofilter system, which has advantages, including easy operation, low sludge production, resistance to fluctuations in wastewater volume and concentration fluctuations, and the effect of temperature reduction on small processing efficiency (Said, 2008). The biofilter media used has varying specific areas and is made of Polypropylene (PP) or Polyethylene (PE). When considering the media used for bacterial growth, attention must be paid to specific gravity, hardness, abrasion resistance, surface roughness, uniformity coefficient, and availability (WEF, 2010).

Who and where will do the method testing of the Prefabricated Wastewater Treatment Plant?

Institutions that test testing methods for the manufacture of septic tanks or small-scale F-WWTPs should be carried out by neutral and experienced institutions to produce optimal results. As an example of what happened in Japan, the test tests were carried out by a laboratory under the auspices of the NIES (National Institute of Environmental Studies), Japan. So, all Johkasous products, before being marketed by the industry, are tested first according to the applicable standards. In addition, in Bangkok, Thailand, a manufacturing septic tank test site is carried out in a laboratory under the auspices of the AIT (Asian Institute of Technology). Tests were prepared on several WWTPs using methods carried out by testing centers in Tsukuba, Japan, and AIT, Bangkok, Thailand, to compile the Test Method for Domestic Wastewater Treatment Plants. This is also done based on the input obtained from Indonesia's FGD results and field conditions.

2. Materials and Methods

The research was conducted in two stages: the first stage was to identify opinion polls by conducting stakeholder meetings in collaboration with ITB and NIES; the second stage was to conduct a WWTP prefabrication test using a study of testing methods summarized from methods developed in Indonesia and Japan. In general, the research stages can be seen in Figure 1.

Identification opinion

In the first stage, opinion polls from related institutions were conducted through stakeholder meetings held six times in 2015–2018, with 20–30 participants at every meeting. Participants of the stakeholder meeting are as follows: Inspection body Research Institute for Human Settlements and Housing (RIHS) Ministry of Public Works and Housing, Ministry of Environment and Forestry, Local Government City Planning Agency, and Environmental Agency and NIES (National Institute for Environmental Studies) Japan, Drinking Water and Wastewater Service Company (PDAM) Bandung, PD PAL-Jaya, BPPT, ITB, Manufactures of Decentralized WWTP.

The secondary data from the literature review of the regulation of WWTP management in Indonesia. The data analysis of this study is (a) a comparative study of the certification system of decentralized WWTP in Japan and Indonesia; (b) a descriptive analysis of performance testing method in Indonesia for decentralized WWTP by Inspection Body WWTP RIHS; (c) descriptive analysis from some workshops of institutions' role in wastewater performance; (d) comparison from standard testing for wastewater treatment plants.

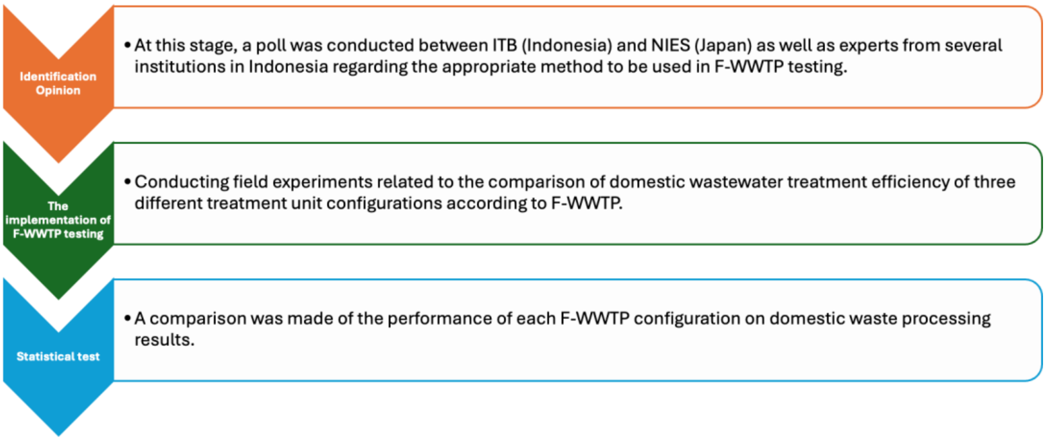
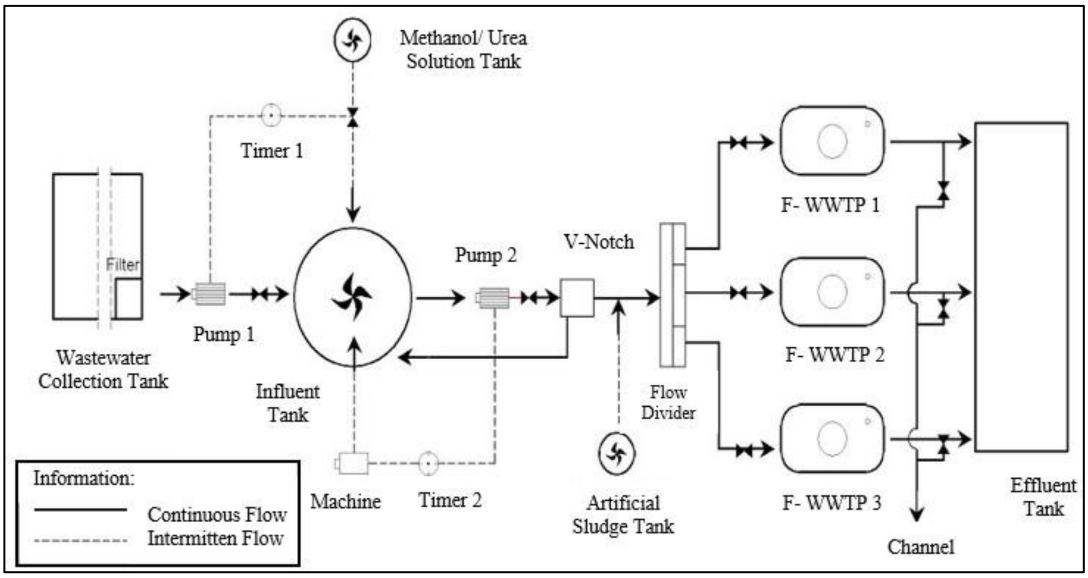


Figure 1. Methodology flowchart.

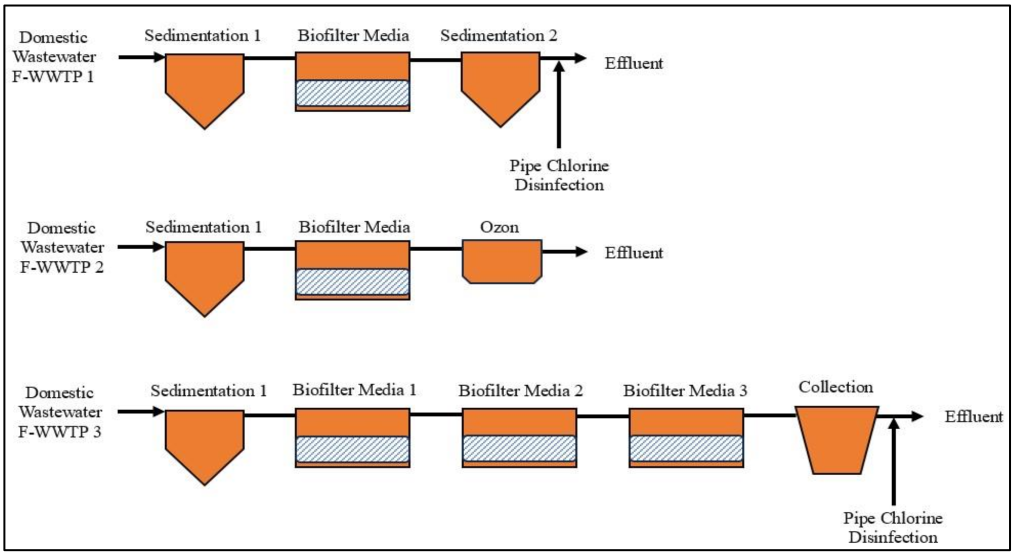
The Implementation of F-WWTP Testing

The primary data collection was done through field observation of testing method performance in Bandung, Indonesia. Three types of F-WWTP with a capacity of 5 persons from different Indonesian manufacturers would be tested. The developed test method has been published as SNI 9161:2023.

The F-WWTP performance testing unit was implemented at the Gumuruh pumping station, PDAM Kota Bandung. The selection of the test location for the test unit is based on fluctuations in the quality of raw water for domestic wastewater in the domestic wastewater collection unit, as well as considerations of surrounding environmental conditions. The F-WWTP performance testing unit consists of a wastewater collection unit, an influent tank, an F-WWTP tank to be tested, an effluent tank, a chemical solution or synthetic sludge dosing unit, and WWTP supporting components. Schematic of F-WWTP performance testing unit, shown in Figure 2.



(a)



(**b**)

Figure 2. (**a**) Unit model for testing the performance of F-WWTP at the location of the Gumuruh Pumping Station in Bandung City; (**b**) schematic of each F-WWTP.

The supporting components for the test unit are adapted to laboratory conditions, such as pumps, flow rate gauges, roofs, and others. The domestic wastewater collection unit receives wastewater, often mixed with rainwater, from the service areas of East Bandung and Central Bandung. Organic and nitrogen contents in the collection unit generally fluctuate and often have low concentrations that require conditioning to meet the criteria for domestic wastewater. Conditioning water quality using chemicals (Methanol, urea) (Li et al., 2011), until it meets the water quality for testing according to Table 2.

Table 2. The characteristic of influent concentration during the research.

Condition	pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	NH_4-N (mg/L)
Minimum	5.8	150	180	120	10
Average	7.2	200	420	160	27.5
Maximum	8.6	350	550	200	45

Figure 3 shows the WWTP installation location where its performance will be tested. The WWTP units are F-WWTP-1, F-WWTP-2, and F-WWTP-3 (Figure 4). The testing stages, which consist of the pre-testing and testing stages, can be seen in Table 3.

Figure 3. The location of the F-WWTP placement during the experiment was at the Gumuruh pumping station, PDAM Kota Bandung.

(**a**) (**b**) (**c**)

Figure 4. Three small scales of F-WWTP: (**a**) F-WWTP-1 (anaerobic biofilter system), (**b**) F-WWTP-2 (anaerobic-aerobic biofilter system), (**c**) F-WWTP-3 (anaerobic-anoxic system).

In the pre-testing stage, the three types of WWTP are installed, and the WWTP manufacturer carries out seeding/acclimatization according to established operating and maintenance standards. This stage takes around 1 to 3 months. During this time, the manufacturer also carefully communicates product operating procedures to operators because manufacturer access to the test unit is not permitted during performance testing. Table 3 shows the stages of F-WWTP testing during this research.

Table 3. The Testing Phase of small scale F-WWTP During Research.

No	The Testing Stages	Duration
I	Pre testing stage	Maximum 12 weeks
1	Additional of artificial sludge	
2	Aclimatitation phane	
II	Testing stage	12 weeks
1	Average flowrate (Q)	8 weeks
2	Peak flowrate (kQ)	1 week
3	Average flowrate (Q)	1 week
4	Minimum flowrate (0.5 Q)	1 week
5	Average flowrate (Q)	1 week

After the seeding/acclimatization stage or stable conditions, the wastewater from the Gumuruh wastewater collection unit is pumped into an influent tank equipped with a stirrer. In the influent tank, methanol and urea are added, using a dose according to the fluctuation in the wastewater quality, and then pumped into the wastewater distribution tank equipped with a v notch. The discharge of wastewater to be treated in 3 F-WWTP units applies the amount of discharge according to the fluctuation of wastewater in Table 4. Furthermore, the wastewater is treated in the F-WWTP unit, which will be tested according to the producer's operating procedure during the testing phase. The treated water from the F-WWTP unit is collected in each effluent tank to analyze physical and chemical parameters.

Table 4. The condition of F-WWTP Performance Testing Discharge.

Time	**% Volume**	**Capacity of F-WWTP (L/day)**		
		F-WWTP-1 (400 L/day)	**F-WWTP-2 (750 L/day)**	**F-WWTP-3 (500 L/day)**
		Discharge Testing (L/hour) (% volume × capacity of WWTP)		
05:00–07:00	16	2.7	5.0	3.3
07:00–09:00	25	4.2	7.8	5.2
09:00–11:00	11	1.8	3.4	2.3
11:00–13:00	8	1.3	2.5	1.7
13:00–15:00	3	0.5	0.9	0.6
15:00–17:00	15	2.5	4.7	3.1
17:00–19:00	13	2.2	4.1	2.7
19:00–21:00	5	0.8	1.6	1.0
21:00–23:00	1	0.2	0.3	0.2
23:00–01:00	0	0.0	0.0	0.0
01:00–05:00	3	0.5	0.9	0.6

Water sampling was carried out on the tested influent tank and F-WWTP effluent. Water quality testing at the acclimatization stage includes organic parameters (COD or BOD) in a composite every week. Performance testing is carried out after the condition is stable; after reaching a minimum of two stable conditions, the acclimatization stage data and the second data can be the beginning of F-WWTP performance testing. Chemical and biological parameters of water quality, including BOD, COD, ammonia, TSS, fatty oil, and Coliform, were tested in the laboratory. A composite sampling of water every week, except for the parameters of oil and fat and Coliform by grab every month when the conditions of the average discharge. Water quality analysis using SNI and Standard method for the examination of water and wastewater 23rd edition 2017. The SNI reference standards used to measure these parameters include the following: BOD (SNI 6989.72:2009); COD (SNI 6989.02:2019); Ammonia (SNI 06-6989.30:2005); TSS (SNI 06-6989.03:2004); oil and grease (SNI 6989.10:2011); and coliform (SNI ISO 9308-1:2010).

In F-WWTP-2, the treatment system is equipped with UV for disinfection, while in F-WWTP-1 and F-WWTP-3, it is equipped with a chlorine disinfectant pipe. Bacteriological parameters are targeted to reach coliforms <3000/100 mL, then F-WWTP products must be equipped with a disinfection unit. In addition to these three WWTPs, we identified 4 other fabricated WWTPs to analyze their characteristics and performance in treating wastewater. The result is that these 4 WWTPs are not yet able to treat organics and nutrients in wastewater, so it is necessary to test the WWTP methods before implementation.

Statistical Test

A one-way ANOVA test was carried out to see the differences in the removal efficiency of each P-WWTP effluent. The null hypothesis is that the average removal from each P-WWTP effluent is the same or there is no significant difference in the removal efficiency value. Then, Hypothesis 1 is that there is a significant difference in the allowance efficiency value for each P-WWTP.

3. Results and Discussion

Level of importance Testing method

To achieve the target of 100% access to domestic wastewater services in Indonesia, the decentralized or non-sewer system is one of the most appropriate alternatives to be developed in Indonesia. Of course, some cities that have developed a centralized system can continue to improve their service development capabilities, such as the cities of Jakarta, Tangerang, Bandung, Cirebon, Jogyakarta, Surakarta, Denpasar, Medan, Prapat, Batam, Balikpapan, Banjarmasin, and Manado. So, more manufacturers are needed to distribute domestic wastewater facilities in Indonesia. However, it is easy to profit if the manufacturer produces poor performance and/or weak tanks. A performance testing method and reliable certification system are required to eliminate low-quality treatment facilities from the market.

Indonesia has not yet regulated certification schemes for decentralized F-WWTP until 2022. Certification schemes are needed to guarantee that the F-WWTP product meets the performance and effluent standards. The development of a decentralized F-WWTP needs regulation regarding the testing body. The Development of a Performance Testing Scheme for Decentralized Domestic Wastewater in 38 provisions of performance testing standards, competent testing body, equipment, and human resources.

The performance testing method and certificate system description include treatment efficiency, tank robustness, material, design, standard operating procedure, power consumption, workshop, and others.

Characteristics of domestic wastewater

Temperature, pH, water content, and the availability of nutrients all have an impact on biodegradation. Nutrition significantly impacts cell synthesis, proliferation, and the activity of enzymes produced by bacteria that break down contaminants. Carbon (C), nitrogen (N), and phosphorus (P) are three key nutrients that bacteria require. Microorganisms use carbon as an energy source for their operations. Nitrogen and phosphorus are key chemicals in cells that regulate microorganism growth activity. These three components must be in the proper proportions to promote bacterial development (Benefield, 1990; Bitton, 1994).

The BOD and COD ratio measurements determine waste water's biodegradability. The usual BOD/COD ratio for untreated home wastewater is 0.40 to 0.53 (Tchobanoglous et al., 2014; Qasim et al., 1999). If the BOD/COD ratio of untreated wastewater exceeds 0.5, it is easier to treat biologically (Winkler et al., 2011). If the BOD/COD ratio is less than 0.3, the wastewater contains hazardous chemicals that are difficult to decompose biologically (Tchobanoglous et al., 2014). When compared to the BOD/COD ratio of domestic wastewater from several other studies in Table 5, such as in Iran (Dehghani et al., 2018), Korea (Kim et al., 2015), and Brazil (Haandeel and Letingga, 1994), the ratio of BOD/COD in this study is similar, with BOD/COD ratios of 0.49, 0.58, and 0.51, respectively. A comparison of the BOD/COD and C:N:P ratio of this study with other studies can be seen in Table 5.

Table 5. Comparison of BOD/COD and C:N:P with Other Studies.

Country	BOD/COD	C:N:P	Reference
Domestic Wastewater Typical [1)]	0.4	100:6.78:1	Tchobanoglous et al., 2014
Domestic Wastewater Typical [2)]	0.53	100:10:1.5	Qasim et al., 1999,
Iran	0.49	100:14.97:1.11	Dehghani et al., 2018
Seoul, South Korea	0.58	-	Kim et al., 2015,
Lahore, Pakistan	0.23–0.4	-	Rizvi, 2011
Pedregal, Brazil	0.51	-	Haandal and Letingga, 1994
Bandung, Indonesia	0.55 ± 0.02	100:11.19:1.09	This Research

The optimal C:N:P ratio in aerobic biodegradation is 100:10:1, while anaerobic biodegradation is 100:5:1 (Tchobanoglous et al., 2014). The average C:N:P ratio was 100:11.19:1.09, somewhat higher than the typical wastewater C:N:P ratio of 100:10:1.5 by Qasim et al. (1999) and Tchobanoglous et al. (2014). 100:6.78:1. WWTP 3 has the C:N:P ratio value that is closest to the normal ratio, 100:10.80:1.07. However, it bears no resemblance to the C:N:P ratio of municipal wastewater in Iran (100:14.97:1.11 (Dehghani et al., 2018) or the BOD:N:P ratio of home wastewater (Fajri et al., 2018). The C:N:P ratio value in the effluent tends to grow in N and P values (Figure 5) due to a relatively small drop in N and P values. Breaking down ammonia into nitrate is not optimal in this WWTP system. Hence, N and P must be eliminated by utilizing anoxic and aerobic systems (Fauzi et al., 2023a; Fauzi et al., 2023b). This system can also remove microplastics (Fauzi et al., 2024).

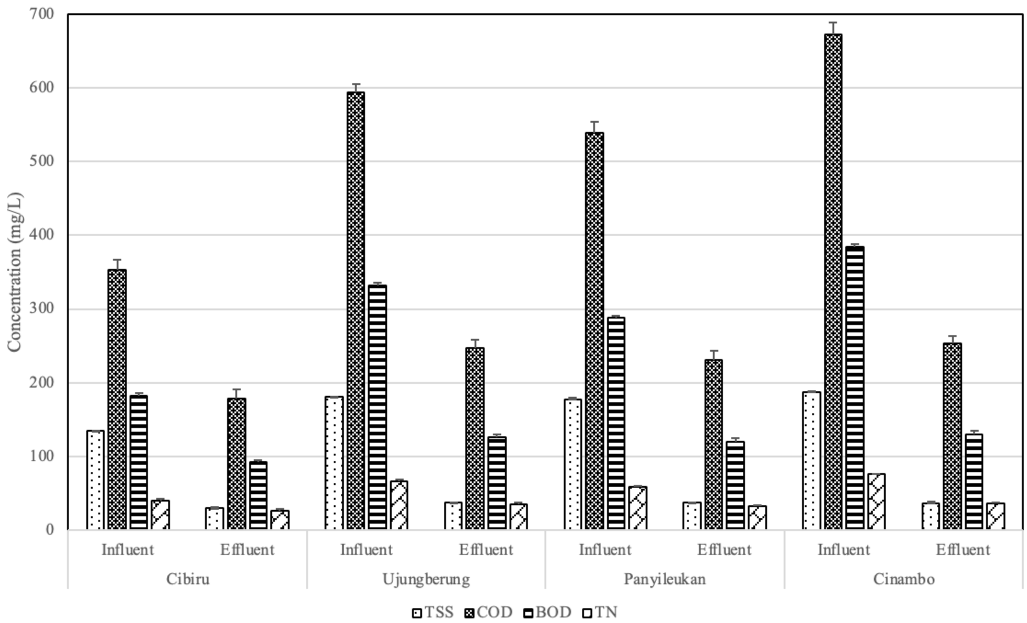


Figure 5. Characteristics of domestic wastewater influent and effluent in several areas in the city of Bandung.

WWTP Performance in Organic and Nutrient Removal

Based on Figure 6 shows that the efficiency of TSS removal is in the range of 77.92%–80.46% with an average of 79.21 ± 1.04%. The highest efficiency is in WWTP 4 (Cinambo), with a TSS value in the resulting effluent of around 36.67 ± 1.53 mg/L, this value is still above the quality standard, which is 30 mg/L in accordance with the applicable quality standard based on PermenLHK No. 68 of 2016 (Appendix 1). This TSS is removed by the sedimentation process that occurs in the WWTP. In this study, the organic removal efficiency ranged from COD of 56.86 ± 5.34% and BOD of 58.96 ± 7.32% with effluents that were still above the quality standards, namely COD (100 mg/L) and BOD (30 mg/L).

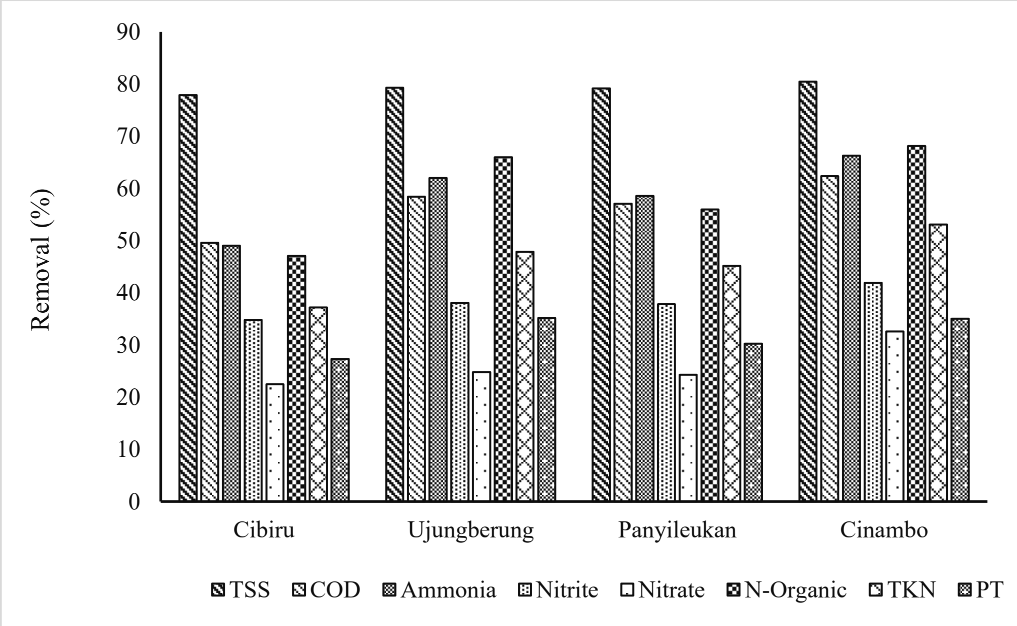


Figure 6. WWTP Performance in Organic and Nutrient Removal.

COD and BOD removal in the WWTP occurs due to the breakdown of complex organic compounds into CO_2 and CH_4. This process occurs under anaerobic conditions. The purpose of this process is to reduce high organic levels first, so as not to interfere with the nutrient removal process. This process occurs with 4 stages, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis which can be seen in Figure 7. (Li et al., 2011; Li et al., 2015). In the hydrolysis stage, complex organic compounds are broken down into simple sugars, amino acids, and long-chain fatty acids. At the acidogenesis stage, these compounds are converted into volatile fatty acids (VFAs) (Propionate and Butyrate). Then at the stage of asedogenesis the compound turns into acetic acid, H_2, and CO_2. The last stage in the methanogenesis stage turns into CH_4 and CO_2.

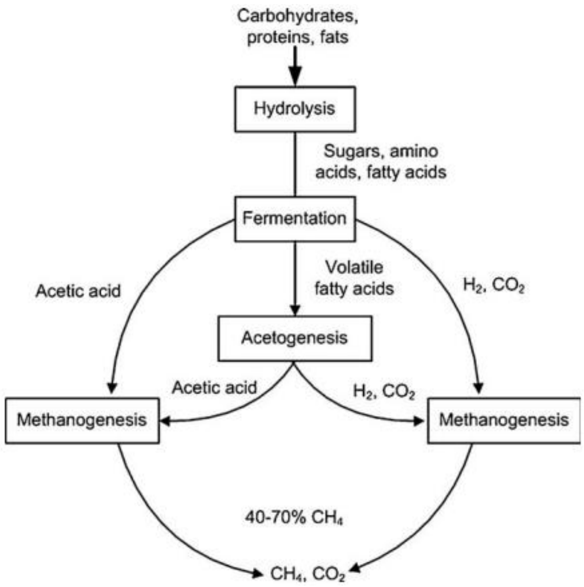


Figure 7. Organic Degradation under Anaerobic Conditions (Li et al., 2011).

The efficiency of ammonia and nitrite removal is low, due to the absence of aerobic processes, where the aerobic process occurs in the process of degrading ammonia into nitrate in the nitrification process (Luther et al., 1997; Hulth et al., 1999). NH_4+ oxidation can produce N_2O or N_2 if NO_2^- oxidation is hindered and NO_2^- is reduced instead (e.g., by denitrifying bacteria) (Barnes et al., 1975). Alternatively, NH_4+ can be oxidized anaerobically by reducing NO_2^- to generate N_2 (anammox process) (Van de Graaf et al., 1995; Thamdrup and Dalsgaard, 2002).

$$2NH_4+ + 3O_2 => 2NO_2- + 4H+ + 2H_2O + \text{New Cell (Nitritization)}$$

$$2NO_2^- + 2O_2 => 2NO_3^- + \text{New Cell (Nitratation)}$$

The low phosphate removal is because the WWTP has anaerobic conditions, so there is no luxury uptake process. Under aerobic conditions, bacteria will accumulate phosphorus so that they are active in absorbing phosphate in the form of polyphosphate and orthophosphate from wastewater (Biyashyna et al., 2010; Wang et al., 2006; Fauzi et al., 2025). There are a number of bacterial species that can use phosphate for their energy source. Phosphate will be absorbed by mycoorganisms as a source of nutrients to help cell growth and proliferation (Shen et al., 2017)

The Fluctuation of Domestic Wastewater

It is known that the wastewater generated in household activities is very dependent on everyone who lives in the house. This depends on everyone's pattern of life, habits, and culture. The study results of the number of households that were observed and then averaged will be displayed in Figure 8. This needs to be done to see to what extent the capability of the WWTP manufacturer is in treating the fluctuation of the wastewater, both quantitatively and qualitatively.

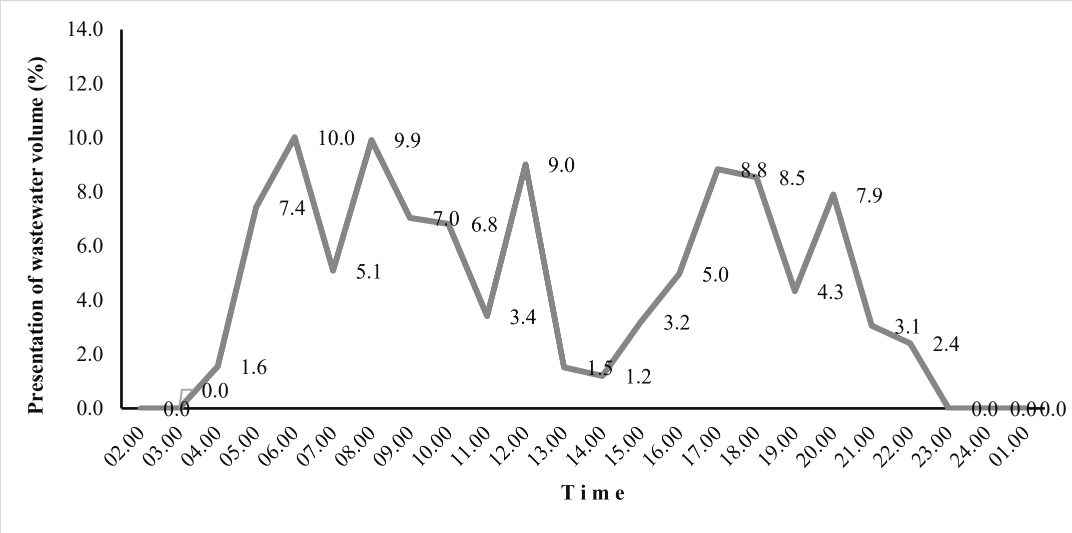


Figure 8. The fluctuation of wastewater in 24 hours from a household.

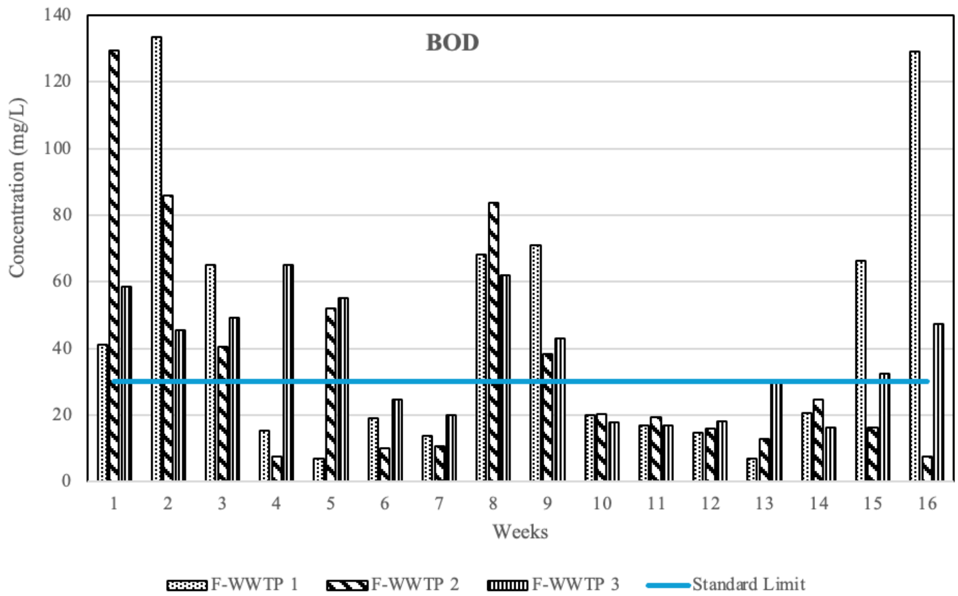
The pattern of wastewater produced at the household scale has two peak hours within 24 hours. The majority of Indonesia's population is Muslim, so there is an indirect relationship during worship that previously required water for ablution.

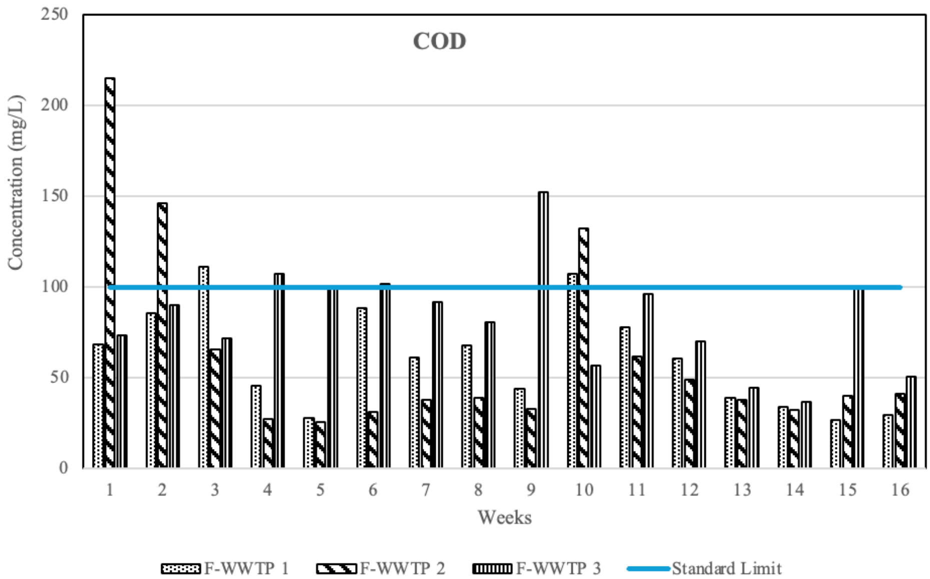
Based on the pattern of liquid waste produced in a household in Figure 6, the fluctuation pattern of liquid waste is used in conducting tests on the three WWTPs (see Table 4).

Comparison of effluent results in F-WWTP

A 12-week experiment was carried out to assess the processing capability of the three WWTP manufacturers. The discharge regulation is adjusted for 24 hours with the percentage of inlet flow according to Table 4, while the concentration of the inlet flow follows Table 2. Figure 9 shows the processing results for the three WWTPs during the trial run.

The type of processing for each F-WWTP combines anaerobic processes with other processes. In F-WWTP 1, anaerobic processing is combined with adding microorganisms every month; F-WWTP 2 is anaerobic processing combined with aerobic and ozone, while in F-WWTP 3, anaerobic processing is combined with anoxic.


BOD
Concentration (mg/L)
0
20
40
60
80
100
120
140
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Weeks
F-WWTP 1
F-WWTP 2
F-WWTP 3
Standard Limit


COD
Concentration (mg/L)
0
50
100
150
200
250
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Weeks
F-WWTP 1
F-WWTP 2
F-WWTP 3
Standard Limit

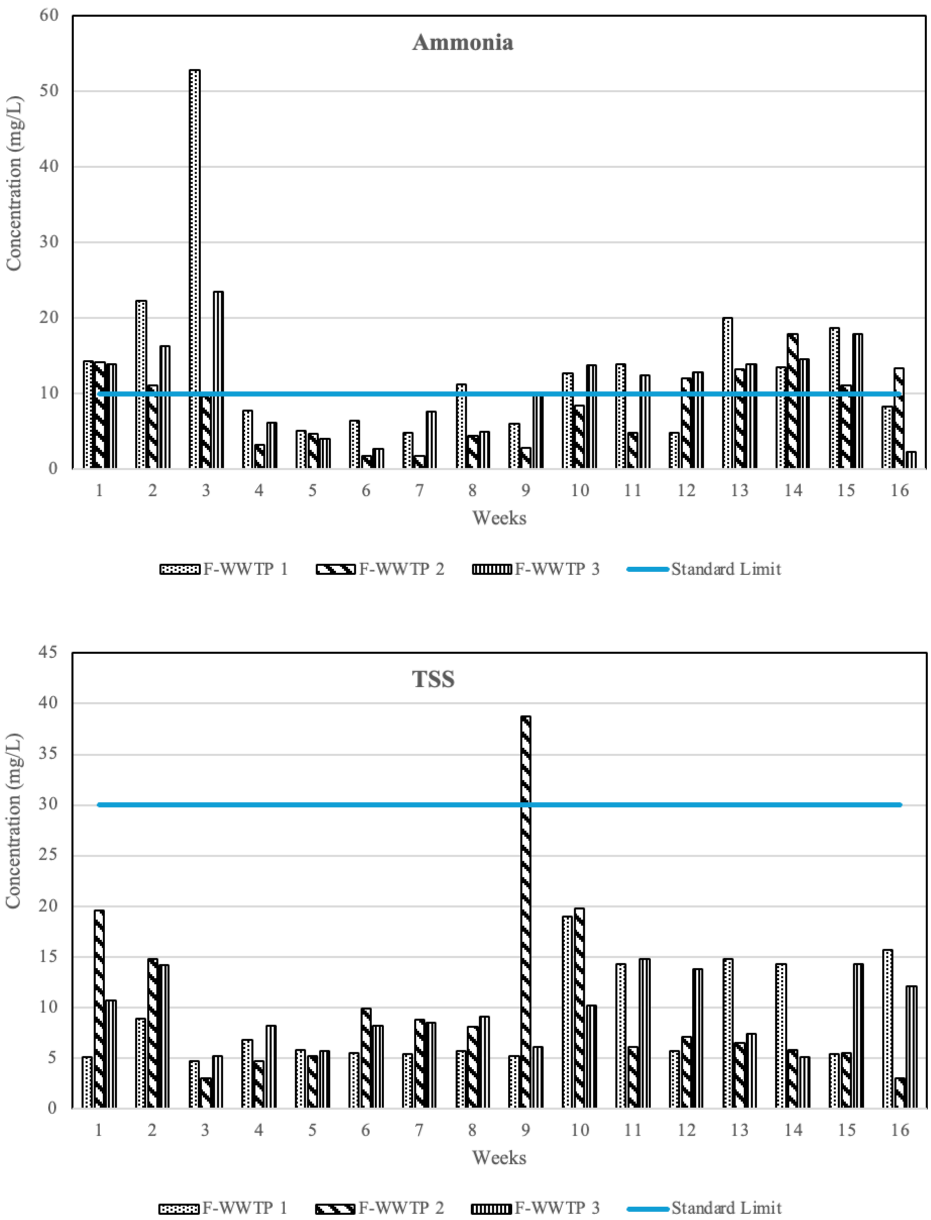


***Figure* 9.** Effluent characteristics of each F-WWTP (Standard limit refers to PerMENLHK Republik Indonesi No. P.68 of 2016).

Based on the results of influent quality monitoring for each F-WWTP for sixteen weeks, the concentrations of COD, BOD, TSS, and ammonia vary quite a lot with an average of 42.70–525.6; 89.8–333.3; 21.2–128, and 5.14–44.0 mgL^{-1} respectively. The same thing can also be seen in the effluent quality, which fluctuates quite a lot from F-WWTP 1, F-WWTP 2, and F-WWTP 3 with a COD concentration of 25.70–215.0; BOD of 7.02–133.3; TSS is 2.98–38.70; and ammonia of 1.76–52.80 at each F-WWTP measured.

To see the difference in the average quality of effluent produced from each F-WWTP, a One-way ANOVA statistical test was carried out with a confidence level of 95% ($\alpha = 0.05$). The amount of data measured from each F-WWTP is 16 ($n = 16$) and the average value to be compared is 3 ($k = 3$) so the critical point value of the F_{table} (0.05; 2; 27) is 3.20. The F_{test} value of the COD, BOD, TSS and ammonia parameters is 1.52; 0.25; 0.23; and 1.79, respectively. Based on the results of these calculations, the F_{test} values for all parameters are below the F_{table}. Thus, it can be concluded that there is no significant difference in the effluent concentration of each parameter in each F-WWTP. In other words, combined domestic waste processing from each F-WWTP does not provide significantly different results for pollutant removal.

The similarity of each type of P-WWTP used is the use of biological processing combined with other processes. Based on the ratios given in the literature, including Heidrich and Witkowski (2005), and Młynski et al. (2016), wastewater with a BOD/COD ratio > 0.5–0.6 can be decomposed easily and effectively through appropriate biological treatment processes. If BOD/COD in wastewater is between 0.4–0.5 and 0.2–0.4, moderate or slow biodegradability may occur. Below < 0.2, wastewater is not susceptible to biodegradation. Meanwhile, the BOD/COD ratio of the waste used in this research is 0.49–0.58, so the pollutant removal process will tend to run quite quickly. The ratio value is taken from the median value in influent BOD and COD measurements, not from the average value because the median value is the value that is considered the most representative for determining wastewater characteristics (Bugajski et al., 2022).

4. Conclusion

Developing and deploying decentralized wastewater treatment systems, such as prefabricated Fabricated-Wastewater Treatment Plants (F-WWTPs), present a viable solution to Indonesia's challenge of achieving 100% access to adequate wastewater services. This study's evaluation of various F-WWTP configurations—anaerobic, anaerobic-aerobic, and anaerobic-anoxic biofilter systems—demonstrates that decentralized systems can meet the necessary effluent quality standards when appropriately managed and maintained.

Key findings indicate that despite the variability in effluent quality across different F-WWTPs, there is no significant difference in their pollutant removal efficiencies. The influent wastewater's average BOD/COD ratio suggests moderate biodegradability, supporting the effectiveness of biological treatment processes used in these systems. However, the study underscores the critical need for a robust performance testing and certification system to ensure the quality and reliability of decentralized wastewater treatment products in the market. Implementing such regulatory measures will help eliminate substandard treatment facilities, protecting environmental and public health.

In conclusion, decentralized systems offer a practical and cost-effective alternative to centralized wastewater treatment in Indonesia. However, continuous technological improvement, stringent quality control, and regulatory oversight are essential for sustainable and efficient wastewater management. Further research is recommended to explore long-term performance and advanced treatment configurations to enhance the efficacy of these systems.

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