Domestic wastewater in Indonesia: generation, characteristics and treatment

Widyarani¹ · Diana Rahayuning Wulan¹ · Umi Hamidah¹ · Ahmad Komarulzaman² · Raden Tina Rosmalina¹ · Neni Sintawardani¹

Received: 10 September 2021 / Accepted: 1 February 2022 / Published online: 12 February 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract

With a 270 million Indonesian population, domestic wastewater is one of the major contributors to wastewater generated from human activities. This review aimed to give an overview of the current state of domestic wastewater generation, characteristics and treatment systems in Indonesia. Overall, grey water quantity in Indonesia was 1 to 4 times higher than black water quantity, while the quantity of untreated grey water was 3 to 6 times higher than untreated black water. Parameters of concern include suspended solids, biochemical oxygen demand, chemical oxygen demand, oil and grease, nitrogen and coliforms. Our analysis shows that grey water can be a significant source of water pollution due to the large quantity and lack of treatment. In addition, black water treatment that relies mainly on on-site treatment is often inadequate due to the lack of quality control for the infrastructure, operation and maintenance. An incentive or penalty scheme to build and ensure the quality of domestic wastewater treatment is required and can be applied at the household, community or central (city) level.

Keywords Black water · Domestic wastewater · Grey water · Indonesia · Off-site treatment · On-site treatment · Wastewater characteristics

Introduction

Domestic wastewater makes up for a large portion of wastewater generated from human activities. Up to 90% of clean water consumption is discharged as wastewater (Ghaitidak and Yadav 2013). The basic access of water consumption for minimum hydration and hygiene is 20 l/c/d, while the optimum access including personal hygiene, food preparation, laundry and bathing requires at least 100 l/c/d (Howard and Bartram 2003). AQUASTAT database reported that municipal water withdrawal from 180 countries in 2017 ranged from 1 to 359 m³/c/year (3 to 978 l/c/d) with a median of

54.3 m³/c/year (149 l/c/d). This mainly comprises water for direct (domestic) consumption, but may also include water for industrial or urban agricultural uses (FAO 2021).

Domestic wastewater is usually divided into two categories, i.e. black water and grey water. Black water is the discharge from toilets that contains high organic, nitrogen and phosphorus content. Grey water is all the other wastewater except the toilet, including from sink, shower and laundry. Grey water volume is one to seven times higher than black water (Ghaitidak & Yadav 2013) and contains relatively low organic compounds, but some of them are considered persistent. Approximately 75% of domestic wastewater is generated from residential buildings or households; the rest are from office buildings, commercial areas, public facilities etc. (Wirawan 2020). Since the type of wastewater-generating activities in households and non-household is similar, domestic wastewater from both sources share similar constituents but are different in composition and quantity (Va et al. 2018).

Indonesia has 153 million population living in the urban area and 117 million in the rural area (BPS 2021a). In urban areas, the total volume of wastewater (domestic, commercial and industrial) and stormwater runoff was estimated to be 14.3 km³/year, while the capacity of municipal wastewater

Responsible Editor: Philippe Garrigues

✉ Widyarani
widyarani@lipi.go.id; widyarani@gmail.com

¹ Research Unit for Clean Technology, National Research and Innovation Agency, Jalan Sangkuriang, Bandung 40135, Indonesia

² Department of Economics, Faculty of Economics & Business, Universitas Padjadjaran, Jalan Dipati Ukur No. 35, Bandung 40132, Indonesia

(a)

(b)

Fig. 1 Distribution of studies in Indonesia: **a** domestic water consumption, **b** domestic wastewater

treatment was only 0.3 km³/year (FAO 2021). The black water is mostly treated in individual or communal septic tanks while the grey water is mostly discharged to water bodies without treatment. Domestic wastewater can reach groundwater and surface water, causing deterioration in water quality and aquatic life (Djuwita et al. 2021). Recent discussions on domestic wastewater in Indonesia mostly focus on treatment technology and management (Firdayati et al. 2015; Harahap et al. 2021). Critical analysis of domestic wastewater characteristics is still limited. There is currently a lack of identification of different impacts of grey water and black water on the environment.

This review aimed to give an overview of the current state of domestic wastewater generation, characteristics and treatment systems in Indonesia. Domestic wastewater generated from households as the major source will be discussed. We will start with a discussion of clean water consumption, and use the data to estimate grey water and black water generation. We follow the discussion with domestic water characteristics, their impact on the environment and the current treatment system. Based on this discussion, we identify the stream with the highest environmental impact.

Methods

Data collection and screening

The current situation in Indonesia regarding water consumption, wastewater generation, wastewater characteristics, wastewater treatment and domestic wastewater in the environment was compiled from scientific journals, proceedings and reports. For scientific literature, online searches were conducted on Scopus and Google Scholar databases with relevant keywords in English and Indonesian including ‘domestic wastewater’, ‘black water’, ‘grey water’, ‘municipal’, ‘households’ and ‘Indonesia’. The literature was then screened, focusing on parameters reported and methods used. Literature from the last 10 years was used whenever possible. After screening, 26 studies on domestic water consumption, 7 studies on grey water, 11 studies on the combined stream of grey water and black water (henceforth referred to as mixed wastewater), and 2 studies on black water were selected. The spatial distribution of these studies is presented in Fig. 1.

In addition, supporting data were also collected from publications by the Food and Agriculture Organization (FAO), the Indonesian Ministry of Health (MoH) and the Indonesian Bureau of Statistics (Badan Pusat Statistik, BPS).

Data processing

Data on water consumption and wastewater characteristics in Indonesia were compiled and analysed with descriptive statistics. If a study had multiple values (e.g. range, multiple measurements over time or from different points in one location), the mean value was used. After compilation, the data are presented as a range (minimum–maximum) or mean $\pm$ SD. Based on proximity and similarities in culture, the data were also compared with studies from four Southeast Asian countries: Thailand, Malaysia, Singapore and Vietnam.

Based on domestic water consumption and domestic wastewater discharge systems, we calculated the material (water) balance and estimated the quantity of treated and untreated domestic wastewater entering the water bodies, particularly surface waters. Material balance was also used to estimate organic load (as chemical oxygen demand, COD) from households entering wastewater treatment plants and water bodies.

Calculation was performed on Microsoft Excel 2016 and jamovi (v.1.6.23) open-source software. The spatial distribution of the reviewed studies was visualised using QGIS (v.3.16.15) open-source software. Sankey diagrams were created using Microsoft Visio 2016.

Limitation of study

Many recent studies on domestic wastewater and related topics in Indonesia, while presenting interesting and possibly valuable data, do not have sufficient quality in research method and reporting to be included in this review. Figure 1 also shows that the selected studies were mostly located in Java Island, with other islands having sparse representatives. This is understandable since Java is an island that has the highest population density compared to other islands in Indonesia, so clean water availability and wastewater discharge from domestic activities are of great concern. In addition, all studies were one-time studies; no long-term studies were included in this review.

Domestic wastewater generation

Domestic water consumption

According to the AQUASTAT database (FAO 2021), the municipal water withdrawal in Indonesia in 2017 was 89.9 m³/c/year (246 l/c/d), amounting to a total of 23.8 km³/year. On the other hand, the production capacity of water companies was 7.0 km³/year (BPS 2021b), which means less than 29% of water demand was met by water companies. The others used groundwater, spring water, surface water and rainwater. For drinking water, notably 39% of the population,

including some of those served by water companies, used bottled water (Komarulzaman et al. 2017; BPS 2021a).

Figure 2 shows domestic water consumption in urban areas ranging from 89 to 244 l/c/d (mean 169 ± 44 l/c/d) and in rural areas ranging from 34 to 194 l/c/d (mean 82 ± 45 l/c/d). On average, urban water consumption already met the optimum water consumption of at least 100 l/c/d (Howard and Bartram 2003), while rural water consumption was still below optimum.

Studies in domestic water consumption in Indonesia were performed via one or a combination of these methods: direct measurement, interview or questionnaire, and water company data. Data from the water company were usually collected by monthly manual meter reading. The automatic water metering system has not been applied widely for recording water consumption (Jawas and Indrianto 2018). In addition, customers of water companies also often use other water sources, for instance, bottled water and groundwater, therefore underestimating the actual water consumption (Komarulzaman et al. 2019).

Figure 2 shows that urban water consumption was significantly higher than rural water consumption. The main contributing factor was the higher income in urban areas compared with rural areas (Andari 2020) since water consumption increases with the increase of income (Hussien et al. 2016). Therefore, consumption for tertiary or luxury activities, such as water for gardening and vehicle cleaning, was also less prominent in the rural areas. In addition, in areas with shared water sources (communal well or spring), water consumption for activities such as laundry or showering was not accounted for because these activities were done at water sources instead of at homes (Messakh et al. 2020). Water scarcity and low rainfall also contributed to the

low water consumption in rural areas and the eastern part of Indonesia (Wini et al. 2020; Messakh and Punuf 2020; Messakh et al. 2020).

Studies in urban areas of Bandung and Surakarta show that water consumption in households connected to water companies was higher than those using other water sources (Suryani et al. 2019; Rahayu et al. 2019). In Bandung City, water consumption of households with water connection (190 ± 251 l/c/d) was essentially similar to households with individual wells (175 ± 204 l/c/d), but higher than those with communal well (66 ± 46 l/c/d) (Suryani et al. 2019). This suggests that accessibility was a determining factor in water consumption. Accessibility might also be a contributing factor in lower water consumption in rural areas, due to lack of water company services coverage.

As shown in Fig. 3, studies performed in several South-east Asian countries show that water consumption varied from 74 l/c/d (Chiang Mai, Thailand, Fig. 3e) to 288 l/c/d (Greater Kuala Lumpur, Malaysia, Fig. 3f). The consumption pattern among Indonesian urban middle-class households (Fig. 3a, b) was relatively similar to those in neighbouring urban areas such as Greater Kuala Lumpur (Fig. 3f) and Singapore (Fig. 3g). In general, water consumption for toilet flushing was the lowest, while the highest water consumption was for shower and ablution purposes. Meanwhile, for meal and dishwashing purposes, the share was approximately the same as for housekeeping purposes. This pattern was relatively consistent between Indonesian urban areas, urban slums, and rural areas, including patterns in cities in neighbouring countries.

In the two Indonesian urban middle-class residential areas (Fig. 3a, b), the water consumption for toilet flushing (37 and 43 l/c/d) was almost similar. Similarly, the study in an Indonesian urban slum area (Fig. 3c) shows that 36 l/c/d was used for toilet flushing. However, while toilet water consumption in the urban middle-class area only accounted for 16–20% of the total water consumption, toilet water consumption in the urban slum accounted for 40% of the total water consumption. The total water consumption in the urban slum (89 l/c/d, Fig. 3c) was almost similar to the study in a rural area (94 l/c/d, Fig. 3d). However, water consumption for toilet flushing in the rural area was 18 l/c/d, lower than all studies in the urban area. Compared with other Southeast Asian countries, water consumption for toilet flushing in rural areas more resembled those in Thailand (Fig. 3e), Singapore (Fig. 3g) and Vietnam (Fig. 3h).

Fig. 2 Boxplots of domestic water consumption in the urban and rural areas. Data from individual studies are presented in Table S1 (Supplementary Information)

Domestic wastewater quantity and discharge

Studies on generated wastewater volume in Indonesia generally used factors 70–90% of clean water usage (Mahatyanta and Razif 2016; Muthiya et al. 2018; Hafiza et al. 2019). To the best of the authors' knowledge, currently, there are no

Fig. 3 Water consumption for toilet flushing (solid black), shower and ablution (solid white), meal and dishwashing (vertical red line), laundry (solid grey) and housekeeping (horizontal green) in **a**, **b** Jakarta Metropolitan Area, urban middle-class (Hafiza et al. 2019; Adriani et al. 2020), **c** Bandung, urban slum (Sintawardani et al. 2005), **d** Banjarnegara, rural (Rachmawati et al. 2020), **e** Chiang Mai (Otaki et al. 2011), **f** Greater Kuala Lumpur (Bari et al. 2015), **g** Singapore (PUB 2021), **h** Hanoi (Otaki et al. 2017)

studies from Indonesia that report on the wastewater generation factor from clean water consumption based on direct measurement. This might be because the automatic water metering system has not been applied widely for recording water consumption and even less so for wastewater generation. Consequently, measurement should be done manually and cannot capture long periods and the fluctuations within.

Based on water consumption in Fig. 3, black water discharge (from toilet flushing) was estimated at 36–43 l/c/d in the urban area and 18 l/c/d in the rural area. Using a factor of 80% for non-toilet water consumption, grey water generation was estimated at 42 l/c/d in urban slums and 137–153 l/c/d in urban middle-class residential. The latter values are in line with a previous study that found grey water generation in urban areas to be 60–178 l/c/d (Firdayati et al. 2015). Moreover, grey water generation in rural areas was estimated at 50 l/c/d. Overall, grey water quantity in Indonesia was one to four times higher than black water quantity, which is consistent with previous studies (Ghaitidak and Yadav 2013).

In Indonesia, black water and grey water are usually separated at the source. Figure 4 shows that 86% of black water in urban areas and 68% in rural areas (overall 79%) are treated in septic tanks. Only 1% of the households are connected to a centralised or communal sewerage system that treats both black water and grey water (BPS 2019). The centralised system is only available in 12 cities and is operated by technical units under municipalities, municipal-owned wastewater management companies or divisions under the water service companies (Harahap et al. 2021). On the other hand, the decentralised wastewater treatment (DEWATS) has been applied under SANIMAS (Sanitasi oleh Masyarakat, Sanitation by Community) program since 2003. The program coverage is more than 15,000 units in 26 provinces.

The implementation varies between locations but typically serves 20–50 households through a simplified sewer network (Eales et al. 2013).

Approximately 5% of black water in urban areas and 24% in rural areas are discharged directly to land holes, which potentially contaminates the groundwater. The failure of providing black water treatment, or even adequate toilets, might be due to lack of funding or technical assistance, area remoteness and geographical conditions, as well as lack of regulation and monitoring (Setiabudi 2021).

Figure 5 shows that only 30% of grey water from the bathroom and laundry and 26% of grey water from the kitchen sink undergo some kind of treatment in open or closed tanks. In urban areas, grey water from the bathroom and laundry (61%) and kitchen sink (65%) is discharged directly to a

Fig. 4 Urban and rural distribution of faecal discharge to the septic tank (solid black), sewer system (solid white), land hole (vertical red line) and others (solid grey) (BPS 2019)

Fig. 5 Urban and rural distribution of grey water from **a** bathroom and laundry discharge and **b** kitchen sink discharge to closed tank (solid black), open tank (solid white), not contained (vertical red line) and ditch/river (solid grey) (MoH 2019)

ditch or river. In rural areas, on the other hand, 38% grey water from the bathroom and laundry and 39% grey water from the kitchen sink are discharged directly to a ditch or river. Overall, 51–53% of grey water in Indonesia is discharged to water bodies without treatment (MoH 2019).

Based on clean water consumption and quantity and discharge systems of black water and grey water in urban and rural areas, we calculated the water balance and estimated the quantity of treated and untreated domestic wastewater entering the water bodies, particularly surface waters (Fig. 6). In both urban and rural areas, the quantity of grey water was estimated to be three times higher than black water. However, the quantity of untreated grey water was approximately six times (urban) and three times (rural) that of black water. The latter consisted of black water that was directly discharged to water bodies and leak from septic tanks. The Ministry of Public Works and Housing estimated that 83% of septic tanks in Indonesia did not meet health and quality standards (Fitri and Alamsyah 2015).

Domestic wastewater characteristics

Table 1 shows the characteristics of grey water, mixed wastewater and black water taken from residential sources in Indonesia and comparison to those in neighbouring countries. Grey water samples were collected at residential outlets (Jiawkok et al. 2013; Suoth and Nazir 2016; Hafiza et al. 2019) or wastewater treatment plant (WWTP) inlets (Astika and Zaman 2017; Marleni et al. 2020). Mixed wastewater samples were collected at WWTP inlets except in three studies (Nagu and Lessy 2020; Al-Ajalin et al. 2020; Ratnawati

and Sugito 2021) where they were collected at residential outlets. Black water samples were collected at residential outlets (Hafiza et al. 2019) and WWTP inlets (Rochmadi et al. 2010). Overall, values for these three types of wastewater are overlapping, and treatment is needed to meet the water quality standard for discharge to water bodies. Variations in values among studies might reflect the actual variation of wastewater characteristics, but also can be attributed to different sampling, storage and analytical methods. Particularly for samples taken from WWTP inlets, values might be influenced by natural degradation, dilution and stormwater infiltration particularly during the rainy season (Semsayun et al. 2015).

pH, TSS and TDS

The pH of grey water, mixed wastewater and black water in Indonesia were between 6.5 and 8.6, 6.7 and 7.5, and 6.2 and 7.4, respectively. Similar values were observed in Thailand, Malaysia, Singapore and Vietnam (Table 1). Overall, these values were within the range of 6–9 in the water quality standard (MoEF 2016). The three types of domestic wastewater tended to have neutral pH due to the dilute stream.

The range of total suspended solids (TSS) and total dissolved solids (TDS) concentrations in grey water was 77–382 mg/l and 152–376 mg/l, respectively (Table 1). In studies reporting both values, TDS tended to be higher than TSS (Suoth and Nazir 2016; Hafiza et al. 2019), but the wide range of values reported makes the trend inconclusive. On the other hand, TSS concentrations in mixed wastewater were between 25 and 1148 mg/l. An even wide range (58–5900 mg/l) was observed in Singapore. The wide

Fig. 6 Estimation of clean water consumption, grey water and black water generations, and discharge into water bodies in urban (a) and rural areas (b). Numbers in m³/d

range might be due to the different proportions between grey water and black water. Also, when samples were taken from WWTP inlets, suspended solids might be precipitated at different rates, thus creating fluctuating TSS concentrations.

Organic compounds

The range of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations in Indonesian grey water was 125–401 mg/l and 232–780 mg/l, respectively (Table 1). As expected, the range of BOD and COD concentrations in black water was higher (206–850 mg/l and 509–2361 mg/l, respectively). BOD concentration (135–480 mg/l) and COD concentration (148–472 mg/l) in mixed wastewater resembled that of grey water, suggesting grey water was more dominant due to its larger volume. Overall, these values exceeded the water quality standard of 30 mg/l for BOD and 100 mg/l for COD (MoEF 2016).

The ratio between BOD and COD in Indonesian grey water was between 29 and 95% (Table 1); the latter value was exceptionally high and might indicate either an overestimation of BOD value or black water contamination. On the other hand, limited studies show that black water was approximately 40% biodegradable. In mixed wastewater, BOD/COD ratio in several studies was higher than 100%, which sometimes occur in streams high in ammonia and due to ammonia oxidation was counted as oxygen consumption

(Polak 2004). Excluding values higher than 100%, the highest BOD/COD ratio in mixed wastewater was 73%.

Hafiza et al. (2019) reported that the highest COD concentration in Indonesian grey water came from laundry (1384 ± 741 mg/l). On the other hand, the highest COD concentration in grey water in Thailand was reported from dishwashing at 990 ± 1500 mg/l (Jiawkok et al. 2013). The high standard deviations indicate high variations from water use and organic compounds source, e.g., residual food, oil and grease.

The range of oil and grease concentration in Indonesian grey water was 24–87 mg/l, within the range of mixed wastewater (2–163 mg/l). As expected, the highest oil and grease concentration was found in grey water sourced from the kitchen sink: 56 ± 73 mg/l in Indonesia (Hafiza et al. 2019) and 200 ± 480 mg/l in Thailand (Jiawkok et al. 2013).

Nitrogen and phosphorus

Ammonia concentration in Indonesia was 0.7–20 mg/l in grey water and 112 mg/l in black water. In mixed wastewater, ammonia concentration was 0.1–259 mg/l; the mean (45 mg/l) was higher but within the same order of magnitude with similar streams in Malaysia (12 mg/l) and Vietnam (36 mg/l) (Al-Ajalin et al. 2020; Tra et al. 2021). Total nitrogen concentration in Indonesia was 59–226 mg/l in grey water, 35–192 mg/l in mixed wastewater and 112 mg/l in black water. The nitrogen concentration of grey water was

Table 1 Characteristics of domestic wastewater in Indonesia and neighbouring countries

Parameter	Unit	WQS ^a	Grey water		Mixed (grey water and black water)			Black water		
			Indonesia ^b	Thailand ^c	Indonesia ^d	Malaysia ^e	Thailand ^f	Singapore ^g	Vietnam ^h	Indonesia ⁱ
pH	–	6–9	6.5–8.6 (7.2 ± 0.8)	7.2 ± 0.4 (6.7–7.5)	7.1 ± 0.3	6.4 ± 0.4	6.7–7.4 (7.0)	6.8–7.6 (7.2)	8.2	6.2–7.4 (6.8 ± 0.8)
TSS	mg/l	30	77–382 (189 ± 115)	69 ± 31	25–1148 (462 ± 357)	14 ± 3	15–243 (58)	58–5900 (771)	36	184–482 (333 ± 211)
TDS	mg/l	–	152–376 (264 ± 159)				124–430 (256)			652–840 (746 ± 133)
BOD	mg/l	30	125–401 (225 ± 96)	90 ± 44	135–480 (271 ± 147)	118 ± 14	12–52 (30)			206–850 (528 ± 455)
COD	mg/l	100	232–780 (418 ± 219)	160 ± 64	148–472 (311 ± 144)	234 ± 20	40–160 (100)	100–4590 (809)	116	509–2361 (1435 ± 1310)
BOD/COD	%	–	29–95 (57 ± 24)		46–149 (89 ± 47)					36–41 (38 ± 3)
Oil and grease	mg/l	5	24–87 (49 ± 33)		2–163 (61 ± 89)		5.3–29 (14)			14
Ammonia (NH ₃ -N)	mg/l	10	0.7–20 (7.5 ± 8.6)		0.1–259 (45 ± 87)	12 ± 0.2			36	112
Total nitrogen	mg/l	–	59–226 (142 ± 119)		35–192 (113 ± 110)		5–20 (10)			19–653 (336 ± 448)
Phosphate (PO ₄ ^{3–} -P)	mg/l	–	10–16 (13 ± 4)		0.4–1.3 (0.8 ± 0.6)	5.0 ± 0.2				
Total phosphorus	mg/l	–	24	1.5 ± 0.9	3–12 (6 ± 5)				6.2	
Faecal coliform	MPN/100 ml	–	2.4 × 10 ³ –1.2 × 10 ⁹ (4.0 ± 6.9 × 10 ⁸)				9.3 × 10 ³ –4.6 × 10 ⁶ (9.1 × 10 ⁵)			9.8 × 10 ⁵
Total coliform	MPN/100 ml	3000			2.6 × 10 ² –1.3 × 10 ⁴ (4.5 ± 7.3 × 10 ³)		3.3 × 10 ⁴ –2.1 × 10 ⁸ (3.2 × 10 ⁷)			
MBAS	mg/l	–	0.2–22 (11 ± 11)	5 ± 4.8						0.1

Empty columns indicate data not available. Numbers within parentheses indicate mean values. Single values indicate results from one study

^aWater quality standard for domestic wastewater (MoEF 2016)

^bKalsum et al. 2014; Firdayati et al. 2015; Suoth and Nazir 2016; Astika and Zaman 2017; Rahmadyanti and Wiyono 2017; Hafiza et al. 2019; Marleni et al. 2020

^cJiawkok et al. 2013

^dLim et al. 2013; Machdar et al. 2014; Astika and Zaman 2017; Wijaya et al. 2017; Rahmawati et al. 2019; Yulistiyorini et al. 2019a, b; Nagu and Lessy 2020; Oktiawan et al. 2021; Nur and Komala 2021; Ratnawati and Sugito 2021

^eAl-Ajalin et al. 2020

^fSensayun et al. 2015

^gWu et al. 2017

^hTra et al. 2021

ⁱRochmadi et al. 2010; Hafiza et al. 2019

– = Not applicable

exceptionally high because a previous study suggests that grey water only contributed 2% of the total nitrogen in domestic wastewater (Malisie et al. 2007). Nitrogen might come from soaps or food residues (Ghaitidak and Yadav 2013).

Phosphate concentration in Indonesia was 10–16 mg/l in grey water and 0.4–1.3 mg/l in mixed wastewater. Total phosphorus concentration in Indonesia was 24 mg/l in grey water and 3–12 mg/l in mixed wastewater. According to Malisie et al. (2007), the contribution of grey water and black water to total phosphorus in domestic wastewater was 11 and 79%, respectively.

Excessive nitrogen and phosphate in the aquatic environment leads to eutrophication, a condition where aquatic plants and algae thrive that leads to an imbalance of aquatic community, blocking of sunlight, oxygen depletion and general deterioration of water quality (Schindler 2006; Kogawa et al. 2017). Phosphate is added to detergents to remove hardness and aid the solubilisation of dirt (Kogawa et al. 2017). Due to its effect on the aquatic environment, phosphate in laundry detergents is largely banned in many countries, particularly in North America and the European Union. Meanwhile, the ban of phosphate in dishwashing detergents is recommended pending the availability of suitable alternatives (McCoy 2011). In Indonesia, the maximum standards for phosphate use are 2%-P in powder detergent (Indonesian National Standard, SNI 4594:2017), 0.5%-P in cream detergent (SNI 0062:2016) and not allowed in liquid detergent for washing machines (SNI 8428:2017), but the implementation is still voluntary (BSN 2019).

Coliforms

The water quality standard for safe disposal of domestic wastewater is 3000 MPN/100 ml of total coliform (MoEF 2016), while the water quality standard for rivers used for irrigation is 2000 MPN/100 ml of faecal coliform (GoI 2021). Furthermore, the World Health Organization (WHO 2006) set the standards for helminth eggs ($< 1/l$) and *E. coli* (< 1000 MPN/100 ml) for irrigation water.

Table 1 shows that the faecal coliform in Indonesian grey water ranged from 2.4×10^3 to 1.2×10^9 MPN/100 ml, while it was 9.8×10^5 in black water. The high value found in grey water might indicate faecal contamination in the grey water system (Firdayati et al. 2015). The total coliform in Indonesian mixed wastewater was 2.6×10^2 – 1.3×10^4 , lower than what was observed in Thailand (3.3×10^4 – 2.1×10^8). In all types of wastewater, the values (as total or faecal coliform) in general had exceeded the water quality standards.

Minerals

Minerals in the wastewater may already be present in the clean water, but can also come from constituents in household products. Sodium, potassium, aluminium and silica

might be present in laundry detergent formulation (Eriksson et al. 2003). On the other hand, chloride was already present at a high concentration in the groundwater in Jakarta Metropolitan Area, probably due to seawater intrusion in the sampling area (Kagabu et al. 2011; Hafiza et al. 2019).

Little attention is given to mineral contents in domestic wastewater due to their low concentration and preceding presence in clean water. Mineral contents should be concerned when grey water is reused, e.g. for housekeeping or agriculture. Mineral contents in grey water should not upset the soil mineral balance that is required to support plant growth (Wakeel 2013). During treatment, some heavy metals might accumulate in the sludge. However, the presence of organic compounds in the sludge and soil plays important role in regulating the bioavailability of these metals and, therefore, application of the sludge as fertiliser is generally considered safe (Usman et al. 2012).

Micropollutants

Micropollutants are compounds that are present in small amounts in wastewater but can still affect the quality of the receiving water bodies. Several types of micropollutants contained in domestic wastewater include surfactants, drugs, hormones and compounds derived from sanitary and personal care products such as fragrances, stabilisers and biocides (Butkovskiy et al. 2017).

Similar to phosphate, surfactants indicate the presence of synthetic detergents, particularly in grey water. Other than surfactants, there is currently no study reporting micropollutants in domestic wastewater in Indonesia. The commonly used surfactants in synthetic detergents are a mixture of alkylbenzene sulfonates (Kogawa et al. 2017). The range of anionic surfactants as methylene blue active substance (MBAS) in grey water was 0.2–22 mg/l (Table 1). Assuming the surfactants consisted mostly of linear alkylbenzene sulfonates (represented by sodium 1-dodecanesulfonate, 2.1 g-COD/g), the observed MBAS concentration is equivalent to 0.3–46 mg-COD/l or 0.05–18% of the total COD in the grey water. Calculated with a similar approach for grey water in Thailand (Jiawkok et al. 2013), the contribution of surfactants was found to be 7% of the total COD in combined grey water, but up to 40% of the total COD in laundry wastewater. Previous studies in the Netherlands and Brazil estimated that surfactants contributed to 15–27% of the total COD in grey water (Hernández Leal et al. 2011; Delforno et al. 2014).

Domestic wastewater in the environment

Domestic wastewater can reach groundwater and surface water via infiltration, leakage or direct discharge. Even when treated, wastewater treatment performance varies

and the effluent might still influence the connected water bodies (Wijaya and Soedjono 2018; UN Habitat and WHO 2021).

Organic compounds

A previous study in Upper Citarum River, a major river in Java passing through West Java and Jakarta Provinces, shows that domestic wastewater contributed to 84% of BOD load to the river (Djuwita et al. 2021). A closer look into smaller segments shows the contribution varied between 50 and 96% depending on the presence of other activities, i.e. livestock farming, fisheries, agriculture and industries. Household BOD contribution had increased from 44–54% in 2000 (Suharyanto and Matsushita 2011), which might be due to increasing population and changes in socio-economic conditions.

Nitrogen and phosphorus

High concentrations of nitrogen and phosphorus in the surface water are associated with eutrophication. The trophic status can be measured by several indicators such as nutrient concentration, phytoplankton abundance, chlorophyll-*a* abundance or a combination of these factors. Not all studies about eutrophication in Indonesia defined clearly the used indicators, nor did they differentiate the source of nutrient loading. However, the contribution of domestic wastewater to nutrient loadings, and consequently eutrophication, should be taken into account particularly when the surface water is connected to settlement areas.

The Saguling Dam, a reservoir to the Upper Citarum River, was already in hyper-eutrophic condition (Marselina and Burhanudin 2017). The main contribution of nitrogen (71%) in Upper Citarum was from agriculture, but domestic wastewater still contributed at 14% (Yoshida et al. 2017).

In incoming rivers to Benoa Bay, Bali Province, some measurements of nitrate and phosphate already indicated eutrophic condition, albeit without clear temporal or spatial pattern (Suteja and Purwiyanto 2018). On the other hand, observation in Benoa Bay itself still showed oligotrophic and mesotrophic indices, although observation on river mouths showed higher trophic indices than in marine water. Furthermore, the study also found abundant (up to 82.5%) potentially harmful algae (Suteja et al. 2021).

Another study in Jepara, a coastal city in Central Java Province, estimated that domestic wastewater contributed to 41% of nitrogen and 35% of phosphorus in groundwater flown into the estuary. Based on nutrient concentration and chlorophyll-*a* abundance, the coastal area was already in moderate to severe eutrophication (Adyasari et al. 2018).

Microorganisms

Microbial profiling and elemental analysis were performed on samples from along the Ciliwung River that passes through West Java and Jakarta Provinces (Duvert et al. 2019). The microbial profile indicated up to 26% contribution of grey water upstream, but less contribution downstream. On the other hand, only a small contribution of black water was detected in all segments. Larger contributions of agriculture and industrial effluents, as well as urban storm-water runoff and riverbed sediments, might be more apparent further down the stream.

Microbial profiling also indicated contamination of domestic wastewater including black water in Citarum River sediment. Notably, microbial diversity decreased in polluted sites (de Jong et al. 2018).

Micropollutants

Chloroxylenol, *N,N*-diethyl-*m*-toluamide (DEET), methyltriclosan, and several pharmaceuticals and aromatic compounds were found in river water in Jakarta Metropolitan Area and seawater in Jakarta Bay (Dsikowitzky et al. 2017). These compounds were constituents or derivatives of personal care products and had been identified in domestic wastewater elsewhere (Eriksson et al. 2003; Butkovskiy et al. 2017). Detection of these compounds was highest in industrial/urban areas, which indicated dominant industrial contribution since some of these compounds were also used in industrial processes. However, the contribution of domestic wastewater should not be neglected (Dsikowitzky et al. 2017). The findings of micropollutants in surface water, despite the current lack of studies on micropollutants in domestic wastewater, highlight the importance of such studies.

Estimation of domestic wastewater in the environment

A previous study in an urban slum estimated that the nitrogen inputs to the river were 5.9 kg/c/year from black water and none from grey water, while the phosphorus inputs were 1.2 kg/c/year from black water and 1.0 kg/c/year from grey water (Ushijima et al. 2013). Modelling of 19 major Indonesian rivers estimated that the total nitrogen and phosphorus inputs from domestic sources in 2000 were 16.8 kt/year and 2.8 kt/year, respectively (Suwarno et al. 2014). From Jakarta alone, the estimation of the total domestic nitrogen input was 14 kt/year and domestic phosphorus input was 5 kt/year in 2012 (van der Wulp et al. 2016). Due to population increase, domestic nitrogen input in 2030 may increase by a factor of 10–12 from input in 2000, while domestic phosphorus input may increase by a factor of 12–16 (Suwarno et al. 2014).

Based on grey water and black water quantities (Fig. 6) and COD concentrations (Table 1), we estimated the COD load in Indonesian urban and rural areas (Fig. 7). Our estimation shows that in urban areas, even though the COD load of black water was higher than grey water, untreated COD load from direct discharges of grey water was higher than combined COD load from septic tank leaks and direct

discharge of black water. It should be noted that in the urban area, COD load from septic tank leak was estimated to be higher than direct discharges of black water. The leak from septic tanks infiltrates the soil and might end up in the groundwater.

In rural areas, septic tank use was lower than in urban areas; therefore, untreated COD load from grey water and

Fig. 7 Estimation of COD discharge from grey water and black water in urban area (a) and rural area (b). Numbers in t/d

black water were almost similar. The COD load from septic tank leaks in rural areas was estimated to be lower than direct discharges of black water.

Current status of domestic wastewater treatment system

In general, the domestic wastewater treatment system can be classified into on-site and off-site systems. Septic tank is the most common (79%) off-site treatment system in Indonesia (BPS 2019). Off-site treatment can be performed in a centralised (city-wide) or decentralised (community-based) system. The first centralised wastewater treatment connected to sewerage system was installed in Bandung, Indonesia in 1916 (Suharyanto and Matsushita 2011), but one century later, only 12 (out of 514) cities have such system (Table 2). All of these cities have less than 50% service coverage, except for Denpasar. Overall, only 1% of the households nationwide are connected to centralised wastewater treatment (BPS 2019).

Given technical, financial and policy barriers for centralised wastewater treatment implementation, decentralised systems can be perceived as a step towards the centralised system, particularly in urban areas. Table 3 shows that with few exceptions, this system had moderate (> 50%) to high removal efficiency for BOD, COD and TSS. Effluent concentrations for these parameters still varied, and values exceeding water quality standards were still observed. For ammonia

and total nitrogen, low removal efficiencies and high effluent concentrations were observed.

Decentralised wastewater treatment systems were usually managed by the community, and sometimes there was a lack of support and a clear management structure to ensure the sustainability of the systems. The system financing relied on user fees that only covered daily operation and did not include desludging and major maintenance (Kerstens et al. 2012; Eales et al. 2013; Harahap et al. 2021).

Discussion

Domestic wastewater is one of the major contributors to wastewater generated from human activities in Indonesia. Even though domestic wastewater quantity is regulated in the water quality standard, most studies estimate wastewater generation from clean water consumption using a factor of 70–90%. There is no study from Indonesia that reports the wastewater generation factor from clean water consumption based on direct measurement. Most studies rely on manual meter reading and secondary data for measurements of clean water consumption, while measurement of wastewater generation was done manually. These methods can capture neither water consumption fluctuations nor wastewater generation over a long period. The automation of water metering systems for water consumption and wastewater generation recording should be encouraged to give a more accurate record, as well as encourage water-saving behaviour for consumers (Gurung et al. 2015).

Table 2 Centralised domestic wastewater treatment in Indonesia

City	Population ^a	Water consumption ^b (l/c/d)	Domestic wastewater ^c (m ³ /day)	WWTP capacity (m ³ /day) ^d		Service coverage (%)
				Installed	Used	
Medan	2,279,894	150	273,587	10,000	5,650	2.1
Parapat	180,694	105	15,178	2,000	115	0.8
DKI Jakarta	10,557,810	150	1,266,937	42,000	5,195	0.4
Bandung	1,263,916	150	151,670	80,835	49,769	33
Cirebon	333,303	105	27,997	20,547	9,667	35
Yogyakarta	431,939	105	36,283	15,500	14,260	39
Surakarta	517,887	135	55,932	9,504	6,325	11
Denpasar	463,400	105	38,926	51,000	35,000	90
Batam	1,196,396	150	143,568	2,852	150	0.1
Banjarmasin	708,606	135	76,529	12,000	3,480	4.5
Balikpapan	688,318	135	74,338	800	800	1.1
Tangerang	1,771,092	150	212,531	2,700	600	0.3

^aFrom local office websites of BPS (www.bps.go.id)

^bClean water planning criteria based on population (MPW 1996)

^cEstimated at 80% of domestic water consumption

^dHarahap et al. 2021

Table 3 Performance of decentralised wastewater treatment plant

Time of study	Location	Number of units	WWTP system	Effluent concentration (mg/l)	Removal efficiency (%)	References
2011	Sleman, Yogyakarta, Surakarta, Blitar	9	ABR-AF (5), AD-ABR-AF (3), AS (1)	BOD: 30–50 COD: 80–131 TSS: 22–44 Ammonia: 35–57 Total nitrogen: 59–88	NA	(Kerstens et al. 2012)
2011	Yogyakarta	2	RBC (1), CA (1)	BOD: 7.5–88 (36) COD: 14–134 (62) TSS: 8–37 (19) Ammonia: 0–1.4 (0.6) Total nitrogen: 173–211 (216)	BOD: 64–96 (81) COD: 76–95 (86) TSS: 85–97 (91)	(Lim et al. 2013)
2016	Semarang	6	ABR + AF (6)	COD: 15–92 (41) TSS: 8–78 (32) Ammonia: 0.01–0.8 (0.4)	COD: 62–93 (85) TSS: 80–95 (87)	(Astika and Zaman 2017)
2018	Yogyakarta	9	ABR (8), RBC (1)	BOD: 12–105 (62) COD: 123–375 (242) TSS: 17–483 (193) Ammonia: 3–38 (20)	BOD: 23–97 (68) COD: 8–77 (52) TSS: 28–79 (53) Ammonia: 3–30 (12)	(Rahmawati et al. 2019)
2018	Malang	89	ABR (89)	BOD: 67	BOD: 74 TSS: 66 Ammonia: 43	(Yulistyorini et al. 2019a)
NA	Yogyakarta	1	AD + ABR (1)	BOD: 22 COD: 61 TSS: 60 Total nitrogen: 4.7	BOD: 88 COD: 97 TSS: 97 Total nitrogen: 75	(Rochmadi et al. 2010)
NA	Padang	5	ABR (5)	BOD: 29–207 (83) COD: 5–106 (18) TSS: 80–724 (128) Ammonia: 46–112 (76)	BOD: 10–72 (24) COD: 45–91 (85) TSS: 17–71 (58) Ammonia: 35–83 (69)	(Nur and Komala 2021)

Numbers within parentheses indicate mean values

NA=data not available, ABR=anaerobic baffled reactor, AD=anaerobic digester, AF=anaerobic filter, AS=activated sludge, CA=contact aeration, RBC=rotating biological contactor

Water quality standard for domestic wastewater quality regulates seven parameters, pH, TSS, BOD, COD, oil and grease, ammonia and total coliform, but most studies only reported parameters pH, TSS, BOD and COD. Other parameters, including those not regulated in water quality standards, were reported sparsely. As shown in Table 1, all types of domestic wastewater, i.e. grey water, mixed wastewater and black water, require treatment to meet the water quality standard for discharge to water bodies. Parameters of concern include suspended solids, BOD, COD, oil and grease, nitrogen and coliforms.

Some constituents of domestic wastewater are present at low concentrations but can be persistent to natural degradation or can disrupt the balance of aquatic life, including surfactants, drugs, hormones, and compounds derived from sanitary and personal care products such as fragrances, stabilisers and biocides. With regards to the COVID-19 pandemic, the use of cleaning products and

disinfectants increases (Toussaint et al. 2020; Vayisoglu and Oncu 2021), and these products also end up in the wastewater, particularly grey water. Other than surfactants, there is currently no study reporting micropollutants in domestic wastewater in Indonesia.

Untreated and poorly treated domestic wastewater can reach groundwater and surface water via infiltration, leakage or direct discharge. Figure 7 indicates that the problem of domestic wastewater pollution in the environment, particularly in urban areas, is mainly attributed to the inadequate on-site treatment of black water and direct discharge of grey water to water bodies.

Application of septic tanks and on-site treatment in general does not have sufficient means to control whether the infrastructure, operation and maintenance meet the specifications. Septic tank installation only requires a small footprint and basic plumbing; therefore, installation cost per capita can be as low as 20% of centralised sewerage system

(Kerstens et al. 2015). The critical point of a septic tank is regular desludging. Unfortunately, this is often ignored by users, resulting in sub-optimal performance (Bao et al. 2020). Due to the lack of spaces in highly populated areas, septic tanks are often located close to shallow groundwater reservoir that is used as a clean water source (Harahap et al. 2021).

In selecting the technology for grey water treatment, the following properties should be considered: high quantity, low–medium organic load and persistent organic contents. Physical processes, e.g. sand filtration, membrane filtration and activated carbon adsorption are effective in removing suspended solids and turbidity but have limited efficiency in organic removal (Li et al. 2009). Aerobic biological treatment has a higher COD removal efficiency compared with anaerobic and combined anaerobic–aerobic treatments (Li et al. 2009; Hernández Leal et al. 2010). The removal efficiency in anaerobic treatment is inhibited by the presence of anionic surfactants, which are mostly biodegradable in aerobic conditions but persistent in anaerobic conditions (Ying 2006; Hernández Leal et al. 2010).

Table 4 shows several considerations in selecting a grey water treatment system. Most Indonesian populations still live in landed houses instead of apartments; therefore, on-site treatment is generally considered for one household (four persons on average). On-site treatment, both for grey water or mixed wastewater, should apply a technology that requires minimum operation and maintenance because these will be done by homeowners instead of skilled technicians. On the other hand, the treatment plant cannot occupy a large area due to limited land, particularly in urban areas. Systems such as infiltration pits or constructed wetlands

for grey water treatment require 1–2 m² per person, while rotating biological contactors require 0.1–0.6 m² per person but more regular maintenance (Fastenau et al. 1990; Beler-Baykal 2015). ‘Johkasou’ is a system that originated from Japan and combines anaerobic and aerobic treatments in an on-site unit. The system originally treats black water but has been developed to treat mixed (grey and black) wastewater. In the Japanese setting, Johkasou is a solution for low-cost domestic wastewater treatment in sparsely populated areas, with installation costs only 10–30% of centralised sewerage system (Katagiri 2017). Despite several demonstration units having been installed in Indonesia, wide application of the system is currently not feasible due to operation and maintenance requirements, as well as the unavailability of domestic unit manufacturers that results in high unit cost (Suharyanto and Matsushita 2010).

Currently, there is neither incentive nor penalty scheme for on-site treatment of grey water. Recycling treated wastewater for non-potable uses might be an incentive for homeowners to install a treatment system, particularly in places with water scarcity. However, tertiary treatments including membrane filtration and disinfection are required to ensure water safety (Li et al. 2009). Another incentive to encourage wastewater treatment is a subsidy scheme (Gaulke 2006).

With less land restriction and options for cost-sharing and subsidy for on-site treatment, off-site systems enable more flexible technology options compared with on-site systems. The effluent of off-site systems can be used for agriculture (Lim et al. 2013). Treatment of mixed wastewater in an anaerobic system can generate sufficient energy in the form of biogas, mostly used for cooking (Eales et al. 2013). Since clean water supply and wastewater treatment are interlinked, integration is necessary not only for centralised systems, as is the current practice, but also for decentralised systems. Users of clean water companies are also potential users of the wastewater treatment system; therefore, the planning of development and improvement of clean water systems should also include wastewater sewerage and treatment systems.

Our review shows that there are currently several knowledge gaps in the overview of domestic wastewater systems and characteristics. Many studies of domestic wastewater in Indonesia are still limited in terms of reported parameters and methodology. To the best of our knowledge, there is currently no long-term study reporting the current domestic wastewater situation in Indonesia. The majority of studies were performed in big cities on Java Island. Given Indonesian diversity from urban to rural areas, community sizes, environmental conditions and culture, more longitudinal studies and studies in regions outside Java are required.

Table 4 Requirement of grey water treatment systems

System	On-site	Off-site
Grey water	Minimum operation and maintenance Small footprint Incentive/subsidy Recycle option (toilet flushing, landscaping)	Flexible technology option Shared cost and/or subsidy for CAPEX and operation/maintenance Reuse option (agriculture)
Mixed wastewater	Minimum operation and maintenance Small footprint Incentive/subsidy Recycle option (landscaping)	Flexible technology option Shared cost and/or subsidy for CAPEX and operation/maintenance Reuse option (agriculture) Energy generation option (biogas from anaerobic digestion)

Conclusion

In this review, we give an overview of the current state of domestic wastewater generation, characteristics and treatment systems in Indonesia. Overall, grey water quantity in Indonesia was one to four times higher than black water quantity. The quantity of untreated grey water is six and three times that of black water in urban and rural areas, respectively. The problem of domestic wastewater pollution in the environment, particularly in urban areas, is mainly attributed to the inadequate on-site treatment of black water and direct discharges of grey water to water bodies. Currently, there is a lack of incentive or penalty scheme for domestic wastewater treatment, whether to ensure the quality of existing on-site (black water) treatment or to build on-site treatment of grey water. To promote grey water treatment and domestic wastewater treatment in general, an incentive or subsidy scheme is required and can be applied at the household, community or central (city) level.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11356-022-19057-6>.

Acknowledgements This work was supported by the Deputy of Scientific Services, the Indonesian Institute of Sciences (LIPI) through the National Priority Research Program 2021. The authors also acknowledge the facilities and scientific support from Advanced Characterization Laboratories Bandung, National Research and Innovation Agency, Republic of Indonesia through ELayanan Sains, Badan Riset dan Inovasi Nasional.

Author contribution W was the main contributor who formulated the idea, performed the literature search and data analysis, and wrote the original draft. DRW and UH provided critical analysis on grey water treatment system. AK provided critical analysis on clean water system. RTR provided critical analysis on domestic wastewater characteristics. NS provided supervision and formulated the discussion. All authors read and approved the final manuscript.

Funding This work was funded by the Deputy of Scientific Services, the Indonesian Institute of Sciences (LIPI) through the National Priority Research Program 2021.

Declarations

Competing interests The authors declare no competing interests.

References

- Adriani RP, Kristanto GA, Pratama MA (2020) Greenhouse gas emission estimations for Depok's (West Java, Indonesia) middle-class household water end-uses. *IOP Conf Ser Earth Environ Sci* 423:012042. <https://doi.org/10.1088/1755-1315/423/1/012042>
- Adyarsari D, Oehler T, Afati N, Moosdorf N (2018) Groundwater nutrient inputs into an urbanized tropical estuary system in Indonesia. *Sci Total Environ* 627:1066–1079. <https://doi.org/10.1016/j.scitotenv.2018.01.281>
- Al-Ajalin FAH, Idris M, Abdullah SRS et al (2020) Effect of wastewater depth to the performance of short-term batching-experiments horizontal flow constructed wetland system in treating domestic wastewater. *Environ Technol Innov* 20:101106. <https://doi.org/10.1016/j.eti.2020.101106>
- Andari Y (2020) Analysis of financial and income disparity between rural-urban areas in Indonesia. *Eko-Reg J Pembang Ekon Wil* 15. <https://doi.org/10.20884/1.erjpe.2020.15.1.1441>
- Astika AUW, Zaman B (2017) Kajian kinerja bak settler, anaerobic baffled reactor (ABR), dan anaerobic filter (AF) pada tiga tipe IPAL di Semarang (Performance assessment in settlers, anaerobic baffled reactor (ABR), and filter anaerobic (AF) on three types of WWTP in Semarang). *J Tek Ling* 6:1–15 (in Indonesian)
- Bao PN, Abfertiawan MS, Kumar P, Hakim MF (2020) Challenges and opportunities for septage management in the urban areas of Indonesia – case study in Bandung City. *J Eng Technol Sci* 52:481–500. <https://doi.org/10.5614/j.eng.technol.sci.2020.52.4.3>
- Bari MdA, Begum RA, Nesadurai N, Pereira JJ (2015) Water consumption patterns in Greater Kuala Lumpur: potential for reduction. *Asian J Water Environ Pollut* 12:1–7. <https://doi.org/10.3233/AJW-150001>
- Belér-Baykal B (2015) Stream segregation in household use: a review of grey water as an alternative source of water and yellow water as an alternative source of fertilizers. *Water Qual Expo Health* 7:27–37. <https://doi.org/10.1007/s12403-013-0105-3>
- BPS (2021a) Statistical yearbook of Indonesia 2021a. Badan Pusat Statistik, Jakarta
- BPS (2021b) Kapasitas produksi potensial perusahaan air bersih menurut provinsi (Potential capacity production of water supply establishment by province). <https://www.bps.go.id/dynamictable/2019/03/13/1591/kapasitas-produksi-potensial-perusahaan-air-bersih-menurut-provinsi-liter-per-detik-2010-2017.html>. Accessed 11 Mar 2021b
- BPS (2019) Welfare statistics 2019. Badan Pusat Statistik, Jakarta
- BSN (2019) Ranah SNI - SNI 4594:2017 Detergen serbuk (Powder detergent). Snivaluasi 13:20–25 (in Indonesian)
- Butkovskyi A, Leal LH, Zeeman G, Rijnaarts HHM (2017) Micropollutants in source separated wastewater streams and recovered resources of source separated sanitation. *Environ Res* 156:434–442. <https://doi.org/10.1016/j.envres.2017.03.044>
- de Jong A, Zaan B van der, Geerlings G, et al (2018) Decrease in microbial diversity along a pollution gradient in Citarum river sediment. *bioRxiv* 357111. <https://doi.org/10.1101/357111>
- Delforno TP, Moura AGL, Okada DY, Varesche MBA (2014) Effect of biomass adaptation to the degradation of anionic surfactants in laundry wastewater using EGSB reactors. *Bioresour Technol* 154:114–121. <https://doi.org/10.1016/j.biortech.2013.11.102>
- Djuwita MR, Hartono DM, Mursidik SS, Soesilo TEB (2021) Pollution load allocation on water pollution control in the Citarum River. *J Eng Technol Sci* 53:210112–210112. <https://doi.org/10.5614/j.eng.technol.sci.2021.53.1.12>
- Dsikowitzky L, Hagemann L, Dwiyoitno, et al (2017) Complex organic pollutant mixtures originating from industrial and municipal emissions in surface waters of the megacity Jakarta—an example of a water pollution problem in emerging economies. *Environ Sci Pollut Res* 24:27539–27552. <https://doi.org/10.1007/s11356-017-0164-2>
- Duvert C, Priadi CR, Rose AM et al (2019) Sources and drivers of contamination along an urban tropical river (Ciliwung, Indonesia): insights from microbial DNA, isotopes and water chemistry. *Sci Total Environ* 682:382–393. <https://doi.org/10.1016/j.scitotenv.2019.05.189>
- Eales K, Blackett I, Siregar R, Febriani E (2013) Review of community-managed decentralized wastewater treatment systems in Indonesia. World Bank, Washington DC

- Eriksson E, Auffarth K, Eilersen A-M et al (2003) Household chemicals and personal care products as sources for xenobiotic organic compounds in grey wastewater. *Water SA* 29:135–146
- FAO (2021) AQUASTAT database. In: AQUASTAT Website. <http://www.fao.org/aquastat/statistics/query/>. Accessed 24 Feb 2021
- Fastenau FA, van der Graaf JHJM, Martijnse G (1990) Comparison of various systems for on-site wastewater treatment. *Water Sci Technol* 22:41–48. <https://doi.org/10.2166/wst.1990.0181>
- Firdayati M, Indiyani A, Prihandrijanti M, Otterpohl R (2015) Greywater in Indonesia: characteristic and treatment systems. *J Tek Lingkung* 21:98–114. <https://doi.org/10.5614/jtl.2015.21.2.1>
- Fitri S, Alamsyah IE (2015) 83 persen tangki septik WC di Indonesia bocor dan tak sehat (83 percent of septic tanks in Indonesia leak and unhealthy). In: Republika Online. <https://republika.co.id/berita/ekonomi/makro/15/08/12/nsxgu7349-83-persen-tangki-septik-wc-di-indonesia-bocor-dan-tak-sehat>. Accessed 21 Aug 2021 (in Indonesian)
- Gaulke LS (2006) On-site wastewater treatment and reuses in Japan. *Proc Inst Civ Eng - Water Manag* 159:103–109. <https://doi.org/10.1680/wama.2006.159.2.103>
- Ghaitidak DM, Yadav KD (2013) Characteristics and treatment of greywater—a review. *Environ Sci Pollut Res* 20:2795–2809. <https://doi.org/10.1007/s11356-013-1533-0>
- GoI (2021) Peraturan Pemerintah Republik Indonesia no. 22 tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup, Lampiran VI Baku Mutu Air Nasional (Regulation of the Government of Indonesia no. 22 year 2021 regarding protection and management of the environment, annex IV national water quality standard)
- Gurung TR, Stewart RA, Beal CD, Sharma AK (2015) Smart meter enabled water end-use demand data: platform for the enhanced infrastructure planning of contemporary urban water supply networks. *J Clean Prod* 87:642–654. <https://doi.org/10.1016/j.jclepro.2014.09.054>
- Hafiza N, Abdillah A, Islami BB, Priadi CR (2019) Preliminary analysis of blackwater and greywater characteristics in the Jakarta Greater Region Area. *IOP Conf Ser Earth Environ Sci* 366:012029. <https://doi.org/10.1088/1755-1315/366/1/012029>
- Harahap J, Gunawan T, Suprayogi S, Widyastuti M (2021) A review: domestic wastewater management system in Indonesia. *IOP Conf Ser Earth Environ Sci* 739:012031. <https://doi.org/10.1088/1755-1315/739/1/012031>
- Hernández Leal L, Temmink H, Zeeman G, Buisman CJN (2011) Characterization and anaerobic biodegradability of grey water. *Desalination* 270:111–115. <https://doi.org/10.1016/j.desal.2010.11.029>
- Hernández Leal L, Temmink H, Zeeman G, Buisman CJN (2010) Comparison of three systems for biological greywater treatment. *Water* 2:155–169. <https://doi.org/10.3390/w2020155>
- Howard G, Bartram J (2003) Domestic water quantity, service level and health. World Health Organization, Geneva
- Hussien WA, Memon FA, Savic DA (2016) Assessing and modelling the influence of household characteristics on per capita water consumption. *Water Resour Manag* 30:2931–2955. <https://doi.org/10.1007/s11269-016-1314-x>
- Jawas N, Indrianto (2018) Image based automatic water meter reader. *J Phys Conf Ser* 953:012027. <https://doi.org/10.1088/1742-6596/953/1/012027>
- Jiawok S, Ittisupornrat S, Charudacha C, Nakajima J (2013) The potential for decentralized reclamation and reuse of household greywater in peri-urban areas of Bangkok: greywater reclamation and reuse. *Water Environ J* 27:229–237. <https://doi.org/10.1111/j.1747-6593.2012.00355.x>
- Kagabu M, Shimada J, Delinom R et al (2011) Groundwater flow system under a rapidly urbanizing coastal city as determined by hydrogeochemistry. *J Asian Earth Sci* 40:226–239. <https://doi.org/10.1016/j.jseas.2010.07.012>
- Kalsum SU, Napoleon ANA, Yudono B (2014) Efektivitas eceng gondok (*Eichhornia crassipes*), hydrilla (*Hydrilla verticillata*), dan rumput payung (*Cyperus alternifolius*) dalam pengolahan limbah grey water (Effectivity of water hyacinth (*Eichhornia crassipes*), hydrilla (*Hydrilla verticillata*), and rumput payung (*Cyperus alternifolius*) in grey water treatment). *J Penelit Sains* 17:20–25. <https://doi.org/10.26554/jps.v17i1.44> (in Indonesian)
- Katagiri T (2017) Introduction Johkasou STP: contribute for Myanmar environment. <https://www.jeces.or.jp/spread/pdf/11Dai%20xiaxis5ws.pdf>. Accessed 2 Jun 2021
- Kerstens SM, Legowo HB, Hendra Gupta IB (2012) Evaluation of DEWATS in Java, Indonesia. *J Water Sanit Hyg Dev* 2:254–265. <https://doi.org/10.2166/washdev.2012.065>
- Kerstens SM, Leusbrock I, Zeeman G (2015) Feasibility analysis of wastewater and solid waste systems for application in Indonesia. *Sci Total Environ* 530–531:53–65. <https://doi.org/10.1016/j.scitotenv.2015.05.077>
- Kogawa AC, Cernic BG, do Couto LGD, Salgado HRN (2017) Synthetic detergents: 100 years of history. *Saudi Pharm J* 25:934–938. <https://doi.org/10.1016/j.jsps.2017.02.006>
- Komarulzaman A, de Jong E, Smits J (2017) The switch to refillable bottled water in Indonesia: a serious health risk. *J Water Health* 15:1004–1014. <https://doi.org/10.2166/wh.2017.319>
- Komarulzaman A, de Jong E, Smits J (2019) Hidden water affordability problems revealed in developing countries. *J Water Resour Plan Manag* 145:05019006. [https://doi.org/10.1061/\(ASCE\)WR.1943-5452.0001051](https://doi.org/10.1061/(ASCE)WR.1943-5452.0001051)
- Li F, Wichmann K, Otterpohl R (2009) Review of the technological approaches for grey water treatment and reuses. *Sci Total Environ* 407:3439–3449. <https://doi.org/10.1016/j.scitotenv.2009.02.004>
- Lim HS, Lee LY, Bramono SE (2013) Community-based wastewater treatment systems and water quality of an Indonesian village. *J Water Health* 12:196–209. <https://doi.org/10.2166/wh.2013.003>
- Machdar I, Matsuura N, Kadera H, Ohashi A (2014) Prospective combined system of UASB and DHS reactor for the treatment of domestic wastewater in Jakarta. *J Water Environ Technol* 12:459–468. <https://doi.org/10.2965/jwet.2014.459>
- Mahatyanta A, Razif M (2016) Alternative design of wastewater treatment plant with anaerobic baffled reactor and anaerobic filter for Romokalisari Flats Surabaya. *Int J ChemTech Res* 9:195–200
- Malisie AF, Prihandrijanti M, Otterpohl R (2007) The potential of nutrient reuse from a source-separated domestic wastewater system in Indonesia – case study: ecological sanitation pilot plant in Surabaya. *Water Sci Technol* 56:141–148. <https://doi.org/10.2166/wst.2007.566>
- Marleni N, Ermawati R, Istiqomah N (2020) Application of combined phytoremediation greywater treatment in a single house. *J Civil EngForum* 7:47–58. <https://doi.org/10.22146/JCEF.58218>
- Marselina M, Burhanudin M (2017) Trophic status assessment of Saguling Reservoir, Upper Citarum Basin, Indonesia Air Soil Water Res 10:1178622117746660. <https://doi.org/10.1177/1178622117746660>
- McCoy M (2011) Goodbye, phosphates. In: Chem Eng News. <https://cen.acs.org/articles/89/i4/Goodbye-Phosphates.html>. Accessed 18 Mar 2021
- Messakh JJ, Fanggidae RE, Moy DL (2020) Perceptions of rural communities towards sustainable water supply in arid tropical regions Indonesia. *IOP Conf Ser Earth Environ Sci* 426:012049. <https://doi.org/10.1088/1755-1315/426/1/012049>
- Messakh JJ, Punuf DA (2020) Study on the accessibility of water sources to meet the water needs of rural communities in semi-arid regions of Indonesia. *IOP Conf Ser Earth Environ Sci* 426:012043. <https://doi.org/10.1088/1755-1315/426/1/012043>

- MoEF (2016) Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia No. 68 Tahun 2016 tentang Baku Mutu Air Limbah Domestik (Regulation of Minister of Environment and Forestry, Republic of Indonesia no. 68 year 2016 regarding domestic wastewater quality standard)
- MoH (2019) Laporan nasional Risetdas 2018 (National report of 2018 basic health research). Ministry of Health, Republic of Indonesia, Jakarta (in Indonesian)
- MPW (1996) Kriteria perencanaan air bersih Ditjen Cipta Karya Dinas PU (Clean Water Planning Criteria, Cipta Karya Directorate General, Public Works Office)
- Muthiya A, Tazkiaturrizki T, Ratnaningsih R (2018) The application of grey water recycling at Gayanti City Apartment, South Jakarta. MATEC Web Conf 197:13005. <https://doi.org/10.1051/matecconf/201819713005>
- Nagu N, Lessy MR (2020) The behavior of coastal communities on management of domestic wastewater in Ternate City, Indonesia. IOP Conf Ser Earth Environ Sci 584:012028. <https://doi.org/10.1088/1755-1315/584/1/012028>
- Nur A, Komala PS (2021) Plastic bottles waste as attached growth media in the removal of organic and nutrients for small-scale wastewater treatment. IOP Conf Ser Mater Sci Eng 1098:052045. <https://doi.org/10.1088/1757-899X/1098/5/052045>
- Oktiawan W, Priyambada IB, Aji S, Budi FS (2021) Effect of current strength on electrocoagulation using Al-Fe electrodes in COD and TSS removal of domestic wastewater. IOP Conf Ser Earth Environ Sci 623:012080. <https://doi.org/10.1088/1755-1315/623/1/012080>
- Otaki Y, Otaki M, Aramaki T (2017) Combined methods for quantifying end-uses of residential indoor water consumption. Environ Process 4:33–47. <https://doi.org/10.1007/s40710-016-0204-9>
- Otaki Y, Otaki M, Sugihara H et al (2011) Comparison of residential indoor water consumption patterns in Chiang Mai and Khon Kaen, Thailand. J - Am Water Works Assoc 103:104–110. <https://doi.org/10.1002/j.1551-8833.2011.tb11457.x>
- Polak J (2004) Nitrification in the surface water of the Włocławek Dam Reservoir. The Process Contribution to Biochemical Oxygen Demand (N-BOD). undefined
- PUB (2021) PUB Singapore's National Water Agency: Save water. In: PUB Singap. Natl. Water Agency. <https://www.pub.gov.sg/savewater>. Accessed 29 Dec 2021
- Rachmawati WS, Suryatmojo H, Ngadisih (2020) Water balance evaluation in Penanggungan hamlet Wanayasa sub district Banjarnegara, district Central Java province. IOP Conf Ser Earth Environ Sci 451:012091. <https://doi.org/10.1088/1755-1315/451/1/012091>
- Rahayu P, Rini EF, Soedwihajono (2019) Domestic water adequacy of Surakarta, Indonesia: is it prone to vulnerability? Environ Urban ASIA 10:81–98. <https://doi.org/10.1177/0975425318821807>
- Rahmadyanti E, Wiyono E (2017) The performance of vertical flow constructed wetland for grey water treatment as the efforts in preserving water resources. Ecol Environ Conserv Pap 23:1909–1916
- Rahmawati S, Yulianto A, Wijayaningrat ATP (2019) Decentralized wastewater treatment performance evaluation based on chemical and physical parameters at Bantul Regency. Yogyakarta MATEC Web Conf 280:03006. <https://doi.org/10.1051/matecconf/201928003006>
- Ratnawati R, Sugito S (2021) Active charcoal and zeolite to reduce COD and ammonia of domestic wastewater. J Wetl Environ Manag 9:63–72. <https://doi.org/10.20527/jwem.v9i2.281>
- Rochmadi R, Ciptaraharja I, Setiadi T (2010) Evaluation of the decentralized wastewater treatment plants in four provinces in Indonesia. Water Pract Technol 5:wpt2010091–wpt2010091. <https://doi.org/10.2166/wpt.2010.091>
- Schindler DW (2006) Recent advances in the understanding and management of eutrophication. Limnol Oceanogr 51:356–363. https://doi.org/10.4319/lo.2006.51.1_part_2.0356
- Semsayun C, Chiemchaisri W, Chiemchaisri C, Patchanee N (2015) Reduction of waterborne microorganisms in treated domestic wastewater for reuse in agriculture: comparison between floating media filter and sand filter. Environ Eng Res 20:403–409. <https://doi.org/10.4491/eer.2015.091>
- Setiabudi W (2021) Interventions for last mile districts: achieving 100% ODF in Pangkep District in South Sulawesi. Sanit Value Chain 5:49. <https://doi.org/10.34416/svc.00052>
- Sintawardani N, Irie M, Astuti JT, et al (2005) Feasibility of introducing the bio-toilet to decrease the water pollution in an open canal: a case study in Kiaracandong slum area in Bandung City. In: Future of Urban Wastewater Systems Decentralisation and Reuse. international Water Association (IWA), Xian, China, pp 101–109
- Suharyanto MJ (2011) Integrated basin-based wastewater management system for water pollution control in an enclosed waterbody of the upper Citarum River Basin, Indonesia: case study of Saguling Reservoir: basin-based wastewater management. Lakes Reserv Res Manag 16:185–193. <https://doi.org/10.1111/j.1440-1770.2011.00473.x>
- Suharyanto, Matsushita J (2010) Constraints analysis in the applicability of Johkasou system to Cirebon City, Indonesia: case investigation for appropriate domestic wastewater treatment system for developing countries. Soc Soc Manag Syst Internet J 6:
- Suoth AE, Nazir E (2016) Characteristic of domestic waste water (grey water) in one of mid level residential area in South Tangerang. Ecolab 10:80–88
- Suryani N, Ichiki A, Shimizu T, Maryati S (2019) Investigation of the water supply system and water usage in urban kampung of Bandung City, Indonesia. J Water Environ Technol 17:375–385. <https://doi.org/10.2965/jwet.18-068>
- Suteja Y, Dirgayusa IGNP, Afdal et al (2021) Identification of potentially harmful microalgal species and eutrophication status update in Benoa Bay, Bali. Indonesia Ocean Coast Manag 210:105698. <https://doi.org/10.1016/j.ocecoaman.2021.105698>
- Suteja Y, Purwiyanto AIS (2018) Nitrate and phosphate from rivers as mitigation of eutrophication in Benoa bay, Bali-Indonesia. IOP Conf Ser Earth Environ Sci 162:012021. <https://doi.org/10.1088/1755-1315/162/1/012021>
- Suwarno D, Löhr A, Kroeze C, Widianarko B (2014) Fast increases in urban sewage inputs to rivers of Indonesia. Environ Dev Sustain 16:1077–1096. <https://doi.org/10.1007/s10668-014-9514-0>
- Toussaint LL, Cheadle AD, Fox J, Williams DR (2020) Clean and contain: initial development of a measure of infection prevention behaviors during the COVID-19 Pandemic. Ann Behav Med 54:619–625. <https://doi.org/10.1093/abm/kaa064>
- Tra V-T, Dang B-T, Binh QA et al (2021) Influence of hydraulic loading rate on performance and energy-efficient of a pilot-scale down-flow hanging sponge reactor treating domestic wastewater. Environ Technol Innov 21:101273. <https://doi.org/10.1016/j.eti.2020.101273>
- UN Habitat, WHO (2021) Progress on wastewater treatment – global status and acceleration needs for SDG indicator 6.3.1. United Nations Human Settlements Programme (UN-Habitat) and World Health Organization (WHO), Geneva
- Ushijima K, Irie M, Sintawardani N et al (2013) Sustainable design of sanitation system based on material and value flow analysis for urban slum in Indonesia. Front Environ Sci Eng 7:120–126. <https://doi.org/10.1007/s11783-012-0460-5>
- Usman K, Khan S, Ghulam S et al (2012) Sewage sludge: an important biological resource for sustainable agriculture and its environmental implications. Am J Plant Sci 3:1708–1721. <https://doi.org/10.4236/ajps.2012.312209>

- Va V, Setiyawan AS, Soewondo P, Putri DW (2018) The characteristics of domestic wastewater from office buildings in Bandung, West Java, Indonesia. *Indones J URBAN Environ Technol* 1:199–214. <https://doi.org/10.25105/urbanenvirotech.v1i2.2826>
- van der Wulp SA, Damar A, Ladwig N, Hesse K-J (2016) Numerical simulations of river discharges, nutrient flux and nutrient dispersal in Jakarta Bay, Indonesia. *Mar Pollut Bull* 110:675–685. <https://doi.org/10.1016/j.marpolbul.2016.05.015>
- Vayisoglu SK, Oncu E (2021) The use of cleaning products and its relationship with the increasing health risks during the COVID-19 pandemic. *Int J Clin Pract* n/a:e14534. <https://doi.org/10.1111/ijcp.14534>
- Wakeel A (2013) Potassium–sodium interactions in soil and plant under saline-sodic conditions. *J Plant Nutr Soil Sci* 176:344–354. <https://doi.org/10.1002/jpln.201200417>
- WHO (2006) WHO guidelines for the safe use of wastewater, excreta and greywater. World Health Organization
- Wijaya IMW, Soedjono ES (2018) Physicochemical characteristic of municipal wastewater in tropical area: case study of Surabaya City, Indonesia. *IOP Conf Ser Earth Environ Sci* 135:012018. <https://doi.org/10.1088/1755-1315/135/1/012018>
- Wijaya IMW, Soedjono ES, Fitriani N (2017) Development of anaerobic ammonium oxidation (anammox) for biological nitrogen removal in domestic wastewater treatment (Case study: Surabaya City, Indonesia). *AIP Conf Proc* 1903:040013. <https://doi.org/10.1063/1.5011532>
- Wini PA, Messakh JJ, Harijono (2020) Analisis peyediaan air bersih pedesaan di Desa Oenoni 1 Kecamatan Amarasi Kabupaten Kupang (Analysis of rural clean water supply in Oenoni Village 1 Amarasi Sub-District, Kupang District). *Batakarang* 1:29–34 (in Indonesian)
- Wirawan SMS (2020) Community preparation for domestic wastewater management development in Jakarta. *Int J Innov Sci Res Technol* 5:133–143
- Wu B, Li Y, Lim W et al (2017) Single-stage versus two-stage anaerobic fluidized bed bioreactors in treating municipal wastewater: performance, foulant characteristics, and microbial community. *Chemosphere* 171:158–167. <https://doi.org/10.1016/j.chemosphere.2016.12.069>
- Ying G-G (2006) Fate, behavior and effects of surfactants and their degradation products in the environment. *Environ Int* 32:417–431. <https://doi.org/10.1016/j.envint.2005.07.004>
- Yoshida K, Tanaka K, Noda K et al (2017) Quantitative evaluation of spatial distribution of nitrogen loading in the Citarum river basin, Indonesia. *J Agric Meteorol* 73:31–44. <https://doi.org/10.2480/agrmet.D-15-00020>
- Yulistyorini A, Camargo-Valero MA, Sukarni S et al (2019a) Performance of anaerobic baffled reactor for decentralized wastewater treatment in Urban Malang. *Indonesia Processes* 7:184. <https://doi.org/10.3390/pr7040184>
- Yulistyorini A, Yuaniar MC, Mujiyono M et al (2019b) The addition of lamella in anaerobic baffled reactor used for decentralized municipal wastewater treatment. *IOP Conf Ser Mater Sci Eng* 669:012052. <https://doi.org/10.1088/1757-899X/669/1/012052>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.