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Factors Influencing Safe Managed Decentralized Wastewater in Citarum Watershed

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Abstract

Indonesia's decentralized domestic wastewater systems face the challenge of low safe access to the fecal sludge treatment facilities. This study identifies factors influencing the improvement of decentralized wastewater, considering fecal sludge practices by the community in Citarum Watershed, Indonesia. The communal treatment at 15 study locations has a service capacity for 30-100 households, use technology of anaerobic baffled reactor, anaerobic-aerobic biofilter, or anaerobic digester. Managed communal wastewater treatment is an average less than 50% of capacity design and results effluent quality with a pollution index score of -22 to -4 or lightly to moderately polluted classification. The fecal sludge pollution index of communal and individual wastewater treatment is 1.8 to 7.8 or lightly to moderately polluted classification. Multivariate analysis method was applied to identify principal components from correlated parameters of observed sustainability aspects. Principal components of the communal wastewater treatment aspect consist of treatment type, capacity, detention time, hydraulic loading, organic loading, influent quality and effluent quality. Principal components of the management and environment aspect consist of water consumption, communal sludge quality, maintenance, community participation, individual wastewater treatment, individual sludge quality, and land use.

Keywords: Domestic wastewater; Fecal sludge; Communal; Community; Principal component

1. Introduction

The lack of access to safe sanitation will increase pollution of the water sources, threats to environmental preservation, and significant risks to human health (Verma *et al.,* 2020). Indonesia's household access to improved domestic wastewater infrastructure is about 74.58%, but safe access was about 7.42% in 2018. The provision of existing fecal sludge treatment facility is less than 20%, indicating low safe access and fecal contamination from wastewater facilities (Ministry of Public Works and Housing, 2019). Most decentralized wastewater treatments have no regular sludge emptying. Therefore, they can leach untreated sludge into the surrounding soil and groundwater (Sotelo *et al.,* 2019). Meanwhile, the sludge is a mixture of partially treated sludge (or septage) and wastewater (Bao *et al.,* 2020). Impacts due to poor sludge management contribute to ineffective domestic wastewater treatment.

The majority of decentralized wastewater treatment systems in both urban and rural areas in Citarum Watershed consist of communal, and on-site or individual systems. Citarum River, as the main river, faces complex water-related problems due to pollution by domestic activities, about 70.13% (Ministry of Environment and Forestry, 2021). Most housing areas in Citarum Watershed depend on groundwater for the water sources, thus improving wastewater treatment and desludging should be a priority (Tayler, 2018).

Safe managed sanitation service targeted by 2030 is not just increasing access to toilets and developing wastewater treatment but also considers fecal sludge management, including emptying to conveyance, treatment, and its reuse. Sludge management is challenging for community-based sanitation which has benefits for population that relies on agriculture (Widianingsih *et al.,* 2019). Enhancing wastewater management through decentralized sludge management will improve public health outcomes in developing countries (Rice *et al.,* 2019). The new management of the decentralized system according to Silva *et al.,* 2018, needs to be designed with caution and an understanding barriers. Considered sustainability aspects in wastewater planning are environmental, social, and economic-based (Vidal *et al.,* 2019). This study aims to identify factors influencing the improvement of decentralized wastewater system in terms of fecal sludge practices integrated with the communal system

2. Materials and Methods

2.1 Description of study location

The study took place at housing areas in Citarum Watershed, West Java Province, Indonesia (Figure 1). The majority of the areas have decentralized wastewater systems consisting of a communal treatment (service for 30-100 households/HH) and individual or on-site treatment (service for one to five HH). There are 15 study locations, that researcher observed each a communal wastewater and individual treatments (two to three facilities) managed for more than five years. Types of managed communal technology are anaerobic baffled reactor (ABR), anaerobic/aerobic biofilter (AB), or anaerobic digester (AD). Observed individual treatments consists of a pit latrine or septic tank located near the communal treatment. In Figure 1, some locations had been designed for water reuse indicated by numbers 1 to 6 and categorized as ‘sanitation care ‘village’ (Rohmat *et al.,* 2020).

2.2 Data collection and analysis

This study identifies aspects and parameters that influence the improvement of decentralized wastewater system from the literature review and stakeholders group discussion. The stakeholders involved were the central government, local government, local community organizations, research institutions, and planning consultants. Observed parameters in this study are derived from sustainability aspect, that are communal wastewater treatment, management, and environmental aspects. The method of data collection and analysis of observed parameters are described below.

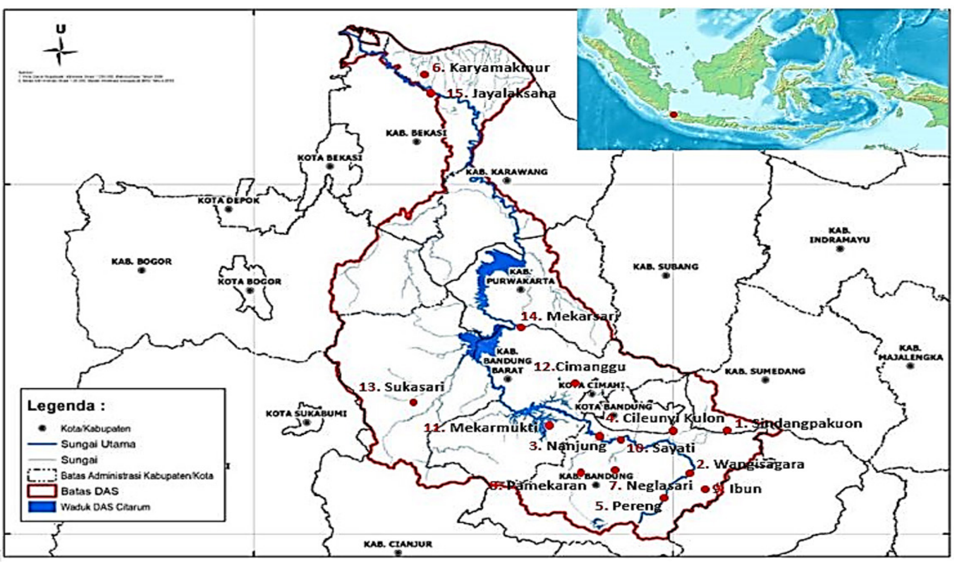


Figure 1. Study locations at Citarum Watershed, Java Province, Indonesia

2.2.1 Communal wastewater treatment aspect

Parameters of the communal wastewater treatment aspect consist of communal treatment type, water supply, and treatment process criteria. Observed parameters were identified by field measurement, interview, and stakeholders' group discussion. Method of parameters analysis uses descriptive and interval rating scale, as in Table 1. The rating scale of the communal system was determined by treatment type, water supply, and treatment process criteria. Each communal treatment process criteria was analyzed by comparing field observation to design criteria according to the manual of wastewater planning.

2.2.2 Influent and effluent of communal treatment

Wastewater quality parameters at influent and effluent of communal treatment were measured by the composite method. The measurement is twice a year for two years of observation, therefore number of wastewater samples are 120 from 15 communal systems. The wastewater quality index is calculated by the storage and retrival of water quality data or STORET method and refers to effluent standard (Ministry of Environment and Forestry, 2016), samples total, and score of water quality parameters. Index of wastewater quality based on the concentration of Total Suspended Solid (TSS), Biochemical

Table 1. Method of evaluation of communal wastewater treatment aspect

Sub-aspect	Parameter	Rating scale	Evaluation
communal system	treatment type	1) conventional type effluent to the river (ABR) 2) upgrading treatment, effluent to the river (AB) 3) upgrading treatment, effluent for reuse (AB/AD and further treatment)	treatment type classified according to the treatment process and target of effluent discharge
	capacity (user/household total)	1) 0-30 % meet capacity design, 2) 31-60%, 3) 61-100%, 4) >100%	the ratio of an existing user to design
	wastewater source	1) not same as design, 2) some as design, 3) same as design	treated wastewater source (black and or grey water)
	volume of treatment	1) 0-35% meet volume design 2) 35-70%, 3) 71-100%	the ratio of existing volume to design
water supply	water consumption	1) 30-70 L/c.day 2) 71-110 L/c.day 3) 110-140 L/c.day	volume of clean water
	water source	1) river, 2) groundwater/water company, 3) groundwater/water company and spring water	water source quality
treatment process criteria	detention time	1) 0-19.9% meet treatment criteria, 2) 20-39.9%, 3) 40-59.9%, 4) 60-79.9%, 5) 80-100%	existing criteria calculation based on field observation compared to design criteria
	organic loading		
	hydraulic loading		

Source: Ministry of Public Works and Housing, 2021

Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammonia, and oil and grease. Scoring of pollution refers to a rating system developed by Canter (1977) as in Table 2 (Barokah *et al.,* 2017).

2.2.3 Fecal sludge quality

Fecal sludge quality was measured to know the pollution level for further evaluation. Sample collection from 15 communal containments use grab sampling method. The sludge from the individual system was sampled at two to three random containments, the total is 34 samples. Measured sludge quality is TSS, Volatile Suspended Solid (VSS), BOD, COD, and ammonia. Pollution Index (PI) method determines the sludge quality index refer to the classification of low strength sludge concentration (Ministry of Public Works and Housing, 2018) and pollution classification as in Table 3 (Hammer and Harper, 2006, Barokah *et al.,* 2017). Measured sludge volume at containment was during sampling then evaluated based on the sludge volume from less than 1/4 to more than 3/4 of containment volume.

2.2.4 Wastewater management and environment aspect

Observed parameters of wastewater management and environment aspect evaluated based on field observation, interviews and documents of government and community organization. The descriptive or interval rating scale of observed parameters in Table 4 that the evaluation was determined through stakeholders discussions at each location.

2.2.5 Factor analysis

The method of multivariate analysis was applied to describe the relationship between different observed parameters with principal components (PC) or factors. The factor analysis method is to analyze 24 parameters (Table 1, 2, 3, and 4) by software of Statistical Product and Service Solutions or SPSS statistic-26. The conversion of ordinal scale to interval scale calculated by Successive Interval Method. Observed parameters are extracted into correlated parameters and identified data patterns by the principal component analysis (PCA) method and factor rotation by the varimax method. Criteria of eigen value, scree plot, and the total amount of variability of original parameters determined the total of PC.

Table 2. Pollution score and quality classification of influent and effluent

Score	Scale	Quality classification
≥ -31	1	Heavily polluted
(-11) – (-30)	2	Moderately polluted
(-1) – (-10)	3	Lightly polluted
0	4	Meet quality standard

Source: Barokah *et al.*, 2017

Table 3. Pollution score and quality classification of fecal sludge

Score	Scale	Quality classification
PI≥ 10	1	Heavily polluted
5.0 ≤ PI ≤ 10	2	Moderately polluted
1.0 ≤ PI ≤5	3	Lightly polluted
0≤ PI ≤1.0	4	Meet quality standard

Source: Barokah *et al.*, 2017

Table 4. Observed parameters of wastewater management and environment

Parameter	Rating scale	Evaluation
- maintenance	1) very poor, 2) poor, 3) fair, 4) good, 5) very good	- treatment unit maintenance, water flow, desludging, sanitation facility
- problem-solving		- water supply, clogging, septic condition, management
- operator skill		- understanding of treatment process, civil structure and process function, management
- operator motivation		- motivation in management and wider pollution prevention
- community participation		- participation in maintenance and retribution
- reuse motivation		- motivation in reuse water or solid
- government support		- training, maintenance, financial support
- impact on water course		- colour or turbidity change, septic condition in river receiving treated water
- land use influence		- flooding, road access or water source disruption in communal facility
- operator total	1) 0-19.9%, 2) 20-9.9%, 3) 40-59.9%, 4) 60-79.9%, 5) 80-100%	- operator total compliances to a design
- on-site/individual wastewater		- volume, containment structure, detention time, desludging period

Source: Ministry of Public Works and Housing, 2021

3. Results and discussion

3.1 Decentralized wastewater treatment

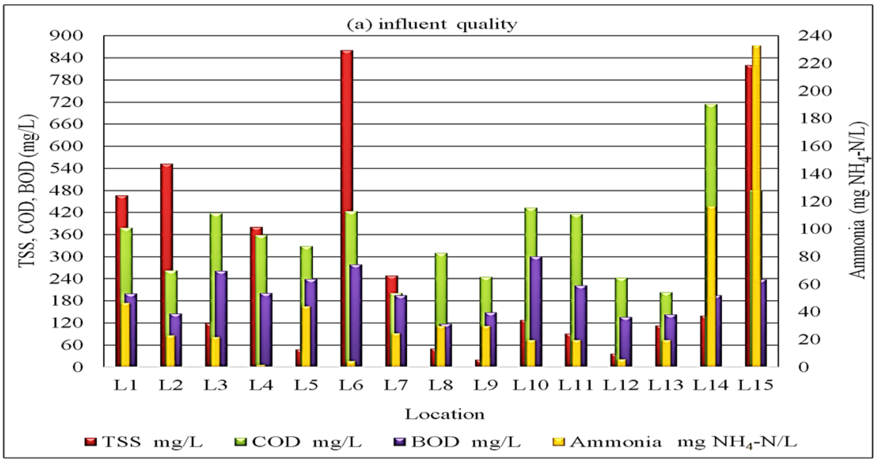
The decentralized treatment category as a technology system follows treatment capacity and proximity to the wastewater source. In terms of community size has the capacity of less than 5000 person equivalent. The wastewater treatment in the decentralized system can consist of communal, cluster, on-site, or individual systems (Sotelo *et al.,* 2019). In Citarum Watershed, about 80.67% decentralized wastewater treatment consists of communal and individual treatment (West Java Province Government, 2019). In study locations, domestic wastewater was treated at communal treatment has concentration of 19 - 860 mg/L TSS, 203-714 mg/L COD, 117 - 300 mg/L BOD, and 6 - 233 mg NH_4-N/L ammonia which an average concentration is as in Figure 2a.

In Figure 2b, some effluent parameters meet national standard (TSS < 100 mg/L, COD < 100 mg/L, BOD < 30 mg/L, ammonia < 10 mg NH_4-N /L) at L1, L2, L5, L11, L12, and L13. The effluent quality from communal treatment has an index pollution score of -22 to -4 which is classified as lightly to moderately polluted. The management of communal facilities in some locations faces problems related to sludge accumulation, water supply, drainage, community awareness, and participation. Desudging practice will influence the effluent quality that poor management will pose a significantly higher risk to the environment while the important water source is groundwater (Mester *et al.,* 2019).

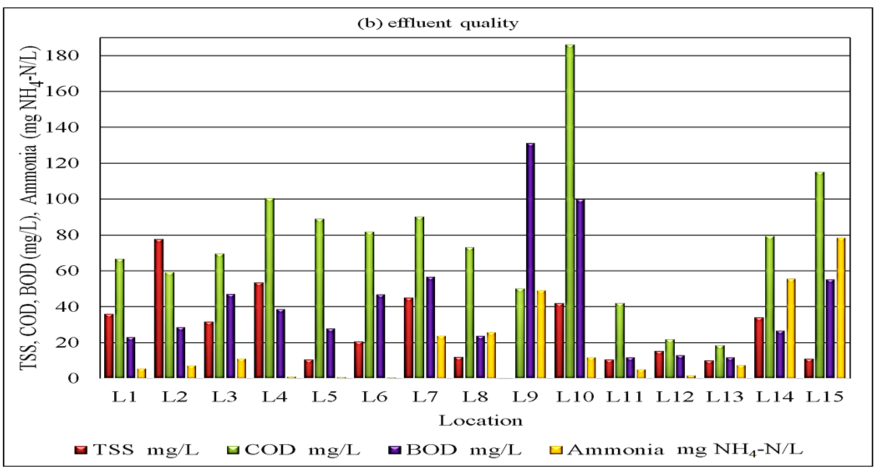
Table 5. Average sludge quality from wastewater treatment

Fecal sludge source	TSS (mg/L)	VSS (mg/L)	BOD (mg/L)	COD (mg/L)	ammonia (mg/L NH_4-N)	water content (%)
communal treatment (30-100 HH)	5887-860,000	273-49356	548-62720	8537.5-97290	76-3446	41-92
septic tank communal (2-10 HH)	3639-5980	66.5-112	19772-41506	30894-64854	230-323	27-77.5
single pit latrine	12442-270 150	498-112 294	4483-40500	7274.6-56250	42-266.3	39.5-95.3
*low strength sludge classification	>7000		COD/BOD =5-10:1	<15000	<10000	

Remarks:* Ministry Public Works and Housing, 2017



(a)



(b)

Figure 2. The average quality of influent (a) and effluent (b) at communal wastewater treatment

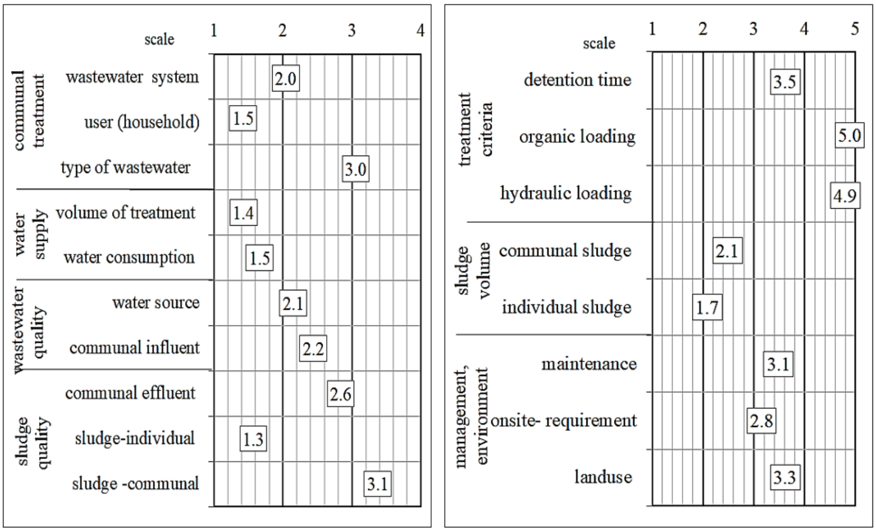


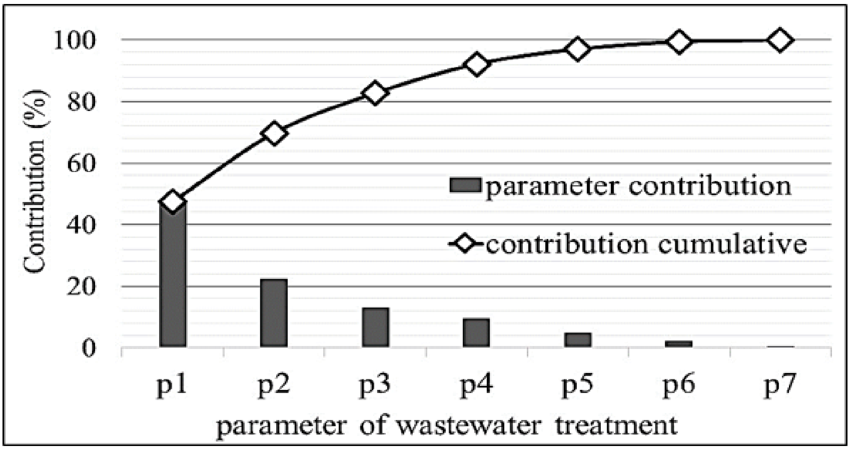
Figure 3. The average scale of observed parameters of decentralized wastewater

The fecal sludge from wastewater treatment has a variety of solid, organic, or nutrient concentrations (Table 5). The sludge quality variation could be due to the containment type that the communal type developed by the government but the community develops pit latrines with an earth bottom, lined or unlined wall. The sludge volume varies greatly depending on the containment type, groundwater infiltration, and emptying frequency (Narayana, 2020). The pollution index score of communal fecal sludge is 1.8 to 7.8 or an average scale of 3.13, while the individual sludge is 2.0 to 6.32 or an average scale of 1.33 (Figure 3). The sludge quality variability is influenced by difference in capture and disposal mechanism (Atwijukye *et al.,* 2016). In study locations, sludge accumulation from communal treatment is about 4.7 - 22.5 L/c.year (L/capita.year), pit latrine or the septic tank is about 1.8 - 41.8 L/c.year. Meanwhile, World Bank 2017's research identified that sludge accumulation in Indonesia at about 23 - 42 L/c.year.

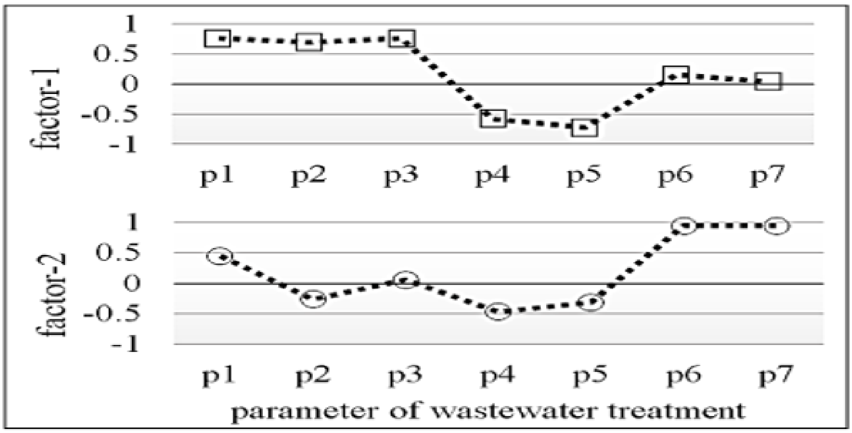
Observed parameters of communal wastewater systems were analyzed by factor analysis method resulted in 19 correlated parameters. The average scale for each parameter of the wastewater treatment system presented in Figure 3. The parameter of communal treatment capacity has an average scale of 1.47 or less than 50% of design. The average effluent of communal treatment has an index of 2.6 or moderately polluted classification. Meanwhile the sludge quality from communal and individual treatment is categorized as slightly polluted. Analyzed treatment process criterias consist of detention time criteria, organic loading, and hydraulic loading, each with an average scale of 3.3, 5.0, and 4.9, or in the range of 60 - 90% meet design criteria. These treatment criteria relied on the reactor type and determined the treatment system's performance (Van *et al.,* 2020). The observed communal sludge volume has an average scale of 2.1 or about 1/3 to 1/2 of the treatment volume. Meanwhile, the individual sludge volume has an average scale of 1.7 or 1/2 - 3/4 of the treatment volume.

3.2 Factors of decentralized wastewater system improvement

The improvement of decentralized wastewater system is in terms of fecal sludge practice with technology development and management integrated with a communal wastewater system. Factor analysis method is applied to identify correlated parameters, as shown in Figure 3, that influence the decentralized system improvement referred to parameters in Tables 1, 2, 3 and 4. Varimax method rotated correlated parameters to know principal components (PC) or factors as in Figures 4 and 5.



(a)

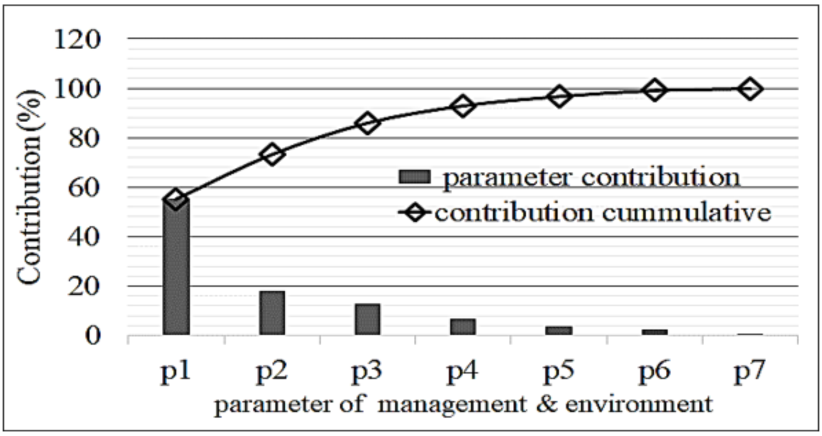


(b)

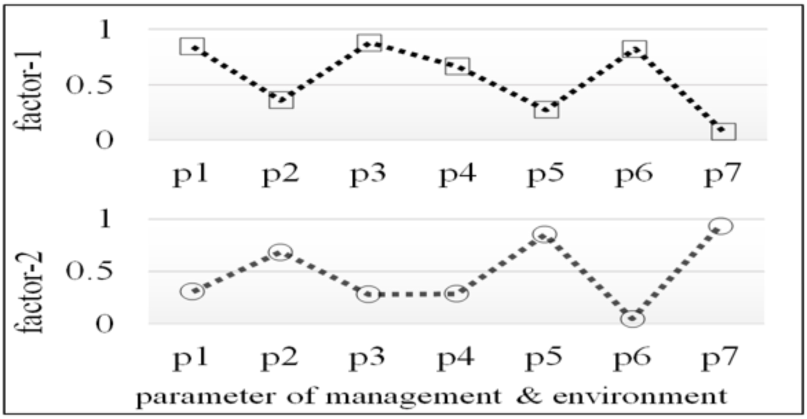
Figure 4. Parameter contribution (a), and loading (b) of wastewater treatment aspect

Factor analysis of communal wastewater treatment aspect resulted seven correlated parameters having different contributions (p1 to p7) as in Figure 4a. The first parameter of treatment type (p1) had a 47.383% contribution to the total variance of the observed aspect. The contribution of the following six parameters was treatment capacity (p2) of 22.325%, detention time (p3) of 13.044%, hydraulic loading (p4) of 9.456%, organic loading (p5) of 4.864%, influent quality (p6) of 2.373%, and effluent quality (p7) of 0.554%. The cumulative contribution of the two most significant factors (eigen value > 1) was 69.708%, indicating that parameters explain almost all the variability from the observed aspect. In Figure 4b, the rotation factor results the loading of each parameter at two PC (significant level $\alpha = 0.05$). Dominant parameters (factor-1) consist of treatment type, capacity, and detention time. Meanwhile, supporting parameters (factor-2) are influent quality, effluent quality, hydraulic loading, and organic loading.

Meanwhile seven correlated parameters were derived from analyzed wastewater management and environment aspect having different contributions as in Figure 5a. The water consumption (p1) had a 55.357% contribution to the total variance of observed aspect. The contribution of the following parameters was communal sludge quality (p2) of 18.004%, maintenance activity (p3) of 12.783%, community participation (p4) of 6.953%, individual wastewater treatment (p5) of 3.783%, individual sludge quality (p6) of 2.404%, and land use (p7) of 0.715%. The factor rotation resulted loading factor



(a)



(b)

Figure 5. Parameter contribution (a), and loading (b) of wastewater management and environment aspect

(significant level $\alpha = 0.05$) in two PC (Figure 5b). Dominant parameters (factor-1) are water consumption, maintenance, community participation, and individual sludge quality. Meanwhile, supporting parameters (factor-2) are communal sludge quality, individual/ on-site treatment, and land use. The research showed that parameter of community participation influences the condition of wastewater infrastructure (Capps, 2020). The influencing factors are also related to maintenance that low community awareness will affect wastewater management (Taweesan *et al.,* 2017).

Implementing a safe decentralized system with integrated fecal sludge practice could develop technology and management, considering factors of communal wastewater treatment, management, and environmental aspects. The development and implementation of public outreach, education, and participation programs, are required for a new decentralized wastewater system (Capps *et al.,* 2020). Technology development can refer to an approach of practice on a communal scale that is directly treating it mixed with wastewater or treated with sludge from communal treatment (Rohilla *et al.,* 2017). Treatment of fecal sludge categorized as moderately to lightly polluted, can be combined with the communal sludge. The sludge categorized as heavily polluted will always be advisable to solid-liquid separation prior to combination-treatment (Keucken *et al.,* 2018). This facility performance limit must be regulated for combined treatment, considering sewer system or infrastructure upgrading (Balasubramanya *et al.,* 2017). Further treatment technologies will be necessary as community awareness increases, which can handle all communities and provide high-quality effluent (Shyu *et al.,* 2021). The plant of integrated wastewater treatment and sludge practice should adapt to local conditions, be easy to operate or maintain, and low cost (Verma *et al.,* 2020). The community should be introduced to sanitation education to raise awareness and to understand better the safe water and fecal sludge management practices (Koottatep *et al.,* 2021).

4. Conclusion

Managed communal wastewater treatments by community at 15 study locations in Citarum Watershed have an average less than 50% of capacity design. The observed communal treatments results effluent quality with a pollution index score of -22 to -4 or lightly to moderately polluted classification. The fecal sludge pollution index of communal and individual wastewater treatment is 1.8 to 7.8 or lightly to moderately polluted classification. The communal treatments process meet about 40 - 90% design criteria of detention time, organic loading, and hydraulic loading.

Factors influencing improvement decentralized wastewater system with integrated fecal sludge practice were identified from aspect of communal wastewater treatment, management, and environment. The factor analysis of observed aspects result principal components or factors could be considered for planning of decentralized system improvement. Principal components of communal wastewater treatment aspect consist of treatment type, treatment capacity, detention time, hydraulic loading, organic loading, influent quality, and effluent quality. Principal components of management and environment aspect consist of water consumption, communal sludge quality, maintenance, community participation, individual wastewater treatment, individual sludge quality, and land use.

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