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IMPLEMENTATION READINESS OF INTEGRATED COMMUNAL WASTEWATER AND FAECAL SLUDGE TREATMENT

Elis Hastuti[1*], Fitrijani Anggraini[2], Maria Fransiska[3], R. Pamekas[4]

[1,2,4] Directorate of Building and Environmental Sanitation Engineering Development, Ministry of Public Works, Jl.Panyaungan, Bandung Regency, West Java

[3] Environmental Engineering and Management, IPB University, Jl. Kumbang No.14, Bogor City, West Java

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Key Words
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Faecal Sludge
Implementation Readiness
Integration
Wastewater

Abstract

Decentralized wastewater treatment systems, which predominate in settlement areas, face challenges in the periodic management of faecal sludge due to limited access to centralized faecal sludge treatment facilities. This study assessed the implementation readiness of communal wastewater treatment plants (WWTPs) integrated with on-site faecal sludge treatment system (SIPALT) in settlement areas within the Citarum Watershed. Wastewater quality was analyzed at 15 communal WWTPs using the Wastewater Quality Index (WWQI), which showed that effluent quality was categorized as moderately to slightly polluted. Faecal sludge from most communal WWTPs indicated low organic pollution according to the Organic Pollution Index (OPI) but high contamination according to the Contamination Index (CI). The performance of most communal WWTPs, assessed using the Overall Equipment Effectiveness (OEE) method, yielded scores above 40%, indicating potential for improvement through SIPALT implementation. Cluster analysis (CA) and multiple discriminant analysis (MDA) were used to prioritize SIPALT technologies and classify implementation readiness into three categories based on technical, environmental, and community-related factors. Communal WWTPs categorized as less ready or not ready for SIPALT implementation require improvements, particularly in effluent quality, water supply, faecal sludge quality, land use, community perceptions, and community participation.

Kata Kunci
Air Limbah
Integrasi
Kesiapan Implementasi
Lumpur Tinja
Pengolahan Komunal

Abstrak

Infrastruktur air limbah desentralisasi yang mendominasi kawasan permukiman menghadapi sejumlah tantangan dalam pengelolaan lumpur tinja secara berkala, diantaranya keterbatasan sarana pengolahan lumpur tinja terpusat. Penelitian ini bertujuan untuk menjelaskan kesiapan implementasi sistem instalasi pengolahan air limbah (IPAL) komunal terintegrasi dengan pengolahan lumpur tinja setempat (SIPALT) di kawasan permukiman Daerah Aliran Sungai Citarum. Analisis pembobotan kualitas air limbah di 15 lokasi IPAL komunal menggunakan metode Wastewater Quality Index (IWWQ), menunjukkan indeks efluen memiliki kategori pencemaran sedang dan ringan. Tingkat pencemaran lumpur tinja dari sebagian besar IPAL komunal mengindikasikan pencemaran ringan berdasarkan organic pollution index (OPI) dan mengindikasikan pencemaran tinggi berdasarkan contaminant Index (CI). Penilaian kinerja IPAL komunal menggunakan metode overall equipment effectiveness (OEE), menunjukkan nilai lebih dari 40% sehingga mempunyai potensi pengembangan SIPALT. Hasil analisis klaster dan analisis diskriminan berganda, mengklasifikasikan prioritas SIPALT dan tiga kategori dalam penilaian kesiapan implementasinya ditinjau dari faktor teknis, lingkungan, dan masyarakat. Sistem IPAL komunal yang dikategorikan kurang siap dan tidak siap implementasi SIPALT membutuhkan perbaikan variabel kualitas efluen, penyediaan air, kualitas lumpur tinja, tata guna lahan, persepsi dan partisipasi masyarakat.

INTRODUCTION

The decentralized wastewater treatment plant in Indonesia represents a significant increase in implementation, with most of the systems depending on communities to maintain them. The rising quantity of faecal sludge generated from decentralized wastewater systems is still challenging in sludge emptying to conveyance, treatment, and its reuse. The communal WWTPs in rural or peri-urban areas are still a source of concern in faecal sludge management because of particularly geographic conditions, management relied on community or limited access to centralized faecal sludge treatment plants.

The target of safe sanitation access is 70% in 2045 as stated on national long term development plan while the safe

*corresponding author: hastutielis@gmail.com

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access achievement is about 10.16% in 2024. Safe access should include the management of faecal sludge from containment and emptying to conveyance, treatment and most importantly, its reuse. The sludge accumulation from wastewater treatment or faecal sludge is as a mixture of partially treated sludge (or septage) and wastewater which are rich in organic compounds and nutrients, contains disease-causing viruses, bacteria and/or parasites (Bao et al., 2020). In general, the wastewater treatment has no regular sludge emptying that can disturb process performance, leach unstable sludge to the surrounding soil, groundwater, or river. Therefore, poor sanitation contributes to ineffective wastewater treatment and will increase pollution to the water source, threaten environmental preservation, and pose significant risks to human health (Tayler, 2018; Verma et al., 2020).

In case of Citarum River, as a main water source for West Java Province and Jakarta, the river has been polluted about 62.16% by domestic activities, including pollution contribution from the decentralized wastewater system (West Java Provincial Government, 2019). Mostly decentralized wastewater treatment plants (WWTP), about 80.67% had been implemented in Citarum's rural and peri-urban area consist of individual systems and communal systems that had been applied widely through Community-Based Sanitation (SANIMAS) Program. The existing integrated centralized Faecal Sludge Management (FSM) and decentralized wastewater management in some settlement areas face challenges related to a lack of availability or access to Faecal Sludge Treatment Plant (FSTP). The effectiveness of existing centralized FSTP is less than 20% and more than 200 cities in 2024 have not been catered by FSTP. To face this challenge, the improvement of decentralized wastewater system is required and can generate benefits for population rely on source of subsistence agriculture.

The efforts to accelerate safe sanitation access in Citarum Watershed' settlement require the integrated management of decentralized wastewater considers variability of spatial settings, sanitation infrastructure, and planning mechanisms. The decentralized solution for wastewater and faecal sludge will result enhancing optimal sanitation and overall community health and environment (Rath et al., 2020). The integrated decentralized wastewater and faecal sludge management is a challenge task because of depends on personal, financial, political, legal, and socio-cultural interactions along the entire service chain (Strande et al., 2018; Chandana & Rao, 2022). The approach of integrated communal wastewater and on-site faecal sludge system (namely in Indonesia as SIPALT) is an option for SANIMAS Program mainly in rural area or peri urban area that have not yet covered or have limited access to centralized FSTP. The SIPALT has a holistic approach to service for entire sanitation chain which consists of collection, treatment, transport, and utilization (Rohilla et al., 2019). The concept of closed loop sanitation in SIPALT complements the previous system as studied by Bernal (2018) that focused on resource recovery and minimum treatment application in accordance with intended end-use. In the SIPALT design incorporates measures to upgrade process or operation units of wastewater or on-site faecal solid treatment that considers local community who will manage it.

The SIPALT management by community consists of a WWTP chain and on-site FSTP followed a series of interrelated activities in operation and maintenance, included financing options and potential income. The communal wastewater treatment at SIPALT system have varied process option that can managed by community. In general, communal treatment consist of anaerobic treatment or combination of anaerobic and aerobic treatment, and can completed by natural filtration or constructed wetland through physical, chemical, or biological system (Putra et al., 2021). Implementation of on-site FSTP in rural area or small city should also consider how human behaviours influence safe and effective management (Patankar et al., 2023). Options for sustainable faecal sludge treatment in SIPALT by community management can comprise batch-operated settling-thickening units, sludge drying beds, constructed wetland, non-aerated stabilization ponds, combined composting with organic waste, or co-treatment with wastewater.

The implementation of SIPALT could be a priority in Citarum Watershed is not only for acceleration of safe access but also provide a protection of groundwater resource and a resource recovery for agriculture. Beside that, most of housing in Citarum Watershed depend on groundwater for the clean water sources thus improving wastewater and faecal sludge management should be a priority (Tayler, 2018). However the implementation of SIPALT within a community organization requires design with caution and an understanding barriers. The sustainability aspect considered in SIPALT planning are environmental, social and economic-based (Vidal et al., 2019).

This study focuses on assessing the implementation readiness of communal WWTP to be improved as SIPALT in settlement areas of Citarum Watershed. The study locations rely on agriculture and mostly have limited access and no availability of centralized FSTP. The effectiveness of communal wastewater treatment system will be identified, and then the implementation readiness of SIPALT will be analyzed according to factors that significantly affect the system improvement. Considered sustainability factors and classification of SIPALT implementation readiness can be references for government guideline in design of existing plant improvement or new plant development of communal wastewater system.

METHOD

The study was conducted at communal WWTPs located in densely populated rural and peri-urban areas of the Citarum Watershed, West Java Province, Indonesia (Figure 1). Primary and secondary data were collected from 15 communal WWTP locations, most of which were

used and managed by local communities. The assessment included 26 variables representing technical aspects and 24 variables representing community aspects. These variables were identified through a literature review, field observations, and focus group discussions involving experts, government representatives, community organizations, and sanitation consultants. The methods used to analyze communal WWTP performance, community characteristics, and SIPALT implementation readiness are described below.

Performance of Communal WWTP

Influent and effluent wastewater quality from communal WWTP were measured by the composite sampling method in 15 study locations for two years of observation at every 6 months. The number of wastewater samples in each location was 8 samples then the total number of samples is 120, which were tested in an accredited laboratory. The wastewater quality parameters observed in influent and effluent are pH, Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), ammonia, oil and grease. At condition where there was a disruption of wastewater treatment process (limited clean water source, pipe clogging, or high sludge accumulation), researchers train the community to maintain them and monitor some repairs until a stable process condition. Data analysis of wastewater quality include comparing influent or effluent data to the wastewater standard, identify deviation standard value, and revealing underlying trends using the moving average method. The Wastewater Quality Index (WWQI) was calculated using Equations (1) to (4):

$$q_n = \left(\frac{V_n - V_{id}}{S_n - V_{id}}\right) x\ 100 \ldots (1)$$

$$W_n = \frac{K}{S_n} \ldots (2)$$

$$K = \frac{1}{\sum \frac{1}{S_n}} \ldots (3)$$

$$WQI = \frac{\sum q_n W_n}{\sum W_n} \ldots (4)$$

q_n: relative value of the n-th parameter based on concentration
V_n: observed water quality of the n-th parameter
S_n: standard permissible value
V_{id}: ideal value for other variables (generally V_{id}=0)
W_n: unit weight to parameter of wastewater quality
K: proportionality constant

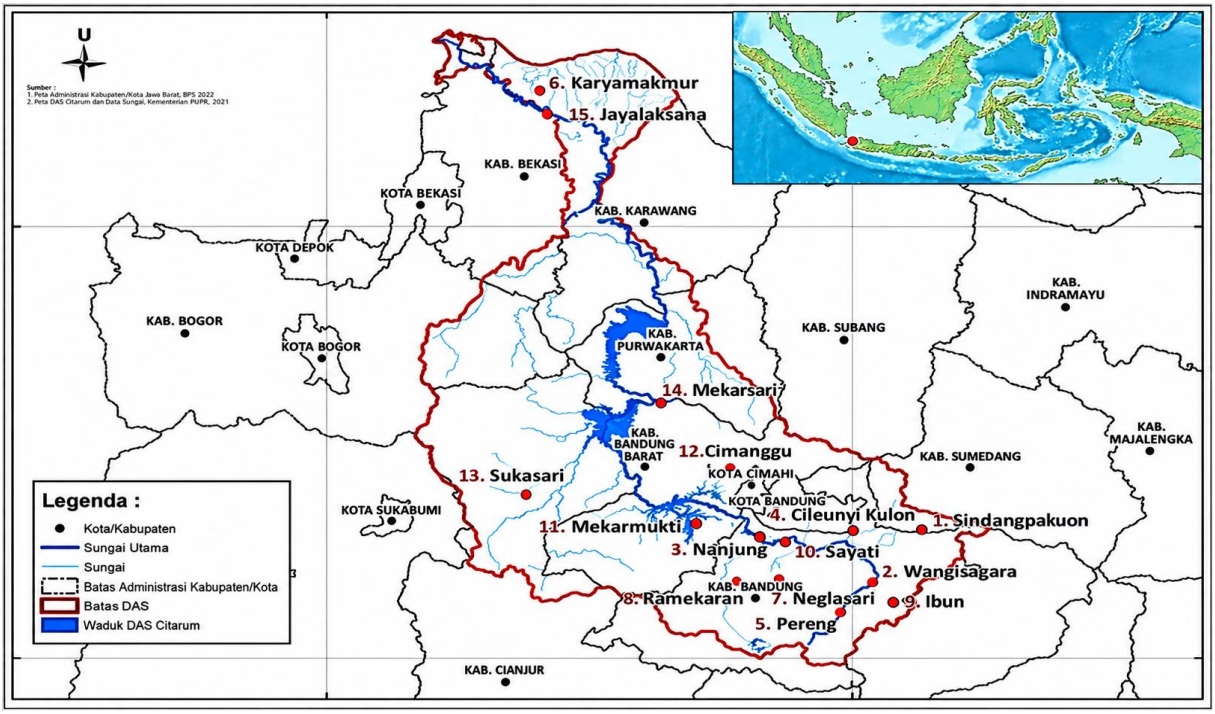


Figure 1. Study location of decentralized wastewater system in Citarum Watershed, Indonesia
Source: West Java Provincial Government, 2019 and processed by author

The analysis of wastewater quality index represents contamination level, which is calculated by the *Weighted Arithmetic Water Quality Index Method* (WAWQIM) based on the Water Quality Index (WQI) method for wastewater and level of wastewater quality (Akpaki et al., 2023). The formula requires three main steps to calculate WQI for wastewater (Equation 4), as determined in Equation 1 to 3. The standard permissible values for each analysis wastewater quality parameter as shown in Table 1. Meanwhile, the WWQI score of influent and effluent in communal WWTP is explained in Table 2.

Table 1. Standard permissible value and weight for wastewater parameter

Parameter	Sn (in)	Sn (ef)	Wi
pH	7, 2	7, 5	0, 13
TSS (mg/L)	160	30	0, 03
COD (mg/L)	365	100	0, 01
BOD (mg/L)	200	30	0, 03
Ammonia (mg/L)	27, 5	10	0, 10
Oil and grease (mg/L)	14, 9	5	0, 20

Source: processed by author
Notes: Sn (in or influent): : Standard National Indonesia (SNI) 9161: 2023
Sn (ef or effluent): Ministry of Environment and Forestry No.68/2016)

In this study, faecal sludge quality was measured with a grab sampling method every year for two years observation to provide an overview of faecal sludge from 15 communal WWTP. The monitoring of faecal sludge pollution described by Organic Pollution Index (OPI) and Contaminant Index (CI). The OPI was dependent on levels of COD, BOD while the CI was dependent on levels of TSS in faecal sludge, as determined by Equation 5 and 6. The permissible value for organic and solid concentration refer to faecal sludge classification (Ministry of Public Works, 2017). The index of faecal sludge was calculated from a number of samples and for each parameter that can be described by OPI, inorganic pollution index or CI (Edori & Kpee, 2016, Akpaki et al., 2023). The OPI wascategorized based on the value of more than 10 (low pollution), 5 - 10 (moderate pollution), or less than 5 (high pollution). The CI wascategorized based on the value less than 1 (low pollution), 1< CI < 3 (moderate pollution), 3 < CI < 6 (considerable pollution), or more than 6 (high pollution).

$$\mathrm{OPI} = \frac{\mathrm{COD_m}}{\mathrm{BOD_m}} \quad \ldots (5)$$

COD_m and BOD_m: measured COD and BOD in faecal sludge

$$\mathrm{CI} = \frac{\mathrm{TSS_m}}{\mathrm{TSS_r}} \quad \ldots (6)$$

TSS_m, and TSS_r: measured TSS and reference concentration in faecal sludge

Table 2. Score of WQI

Scale	Score	Classification
Influent index		
1	>157	Poor/high pollution
2	127-157	Moderate pollution
3	98-127	Light pollution
4	<98	Conformity to standard
Effluent index		
1	>105	Poor/high pollution
2	85-105	Moderate pollution
3	65-85	Light pollution
4	<65	Conformity to standard

Source: processed by author

The effectiveness of communal WWTPs were analyzed by the Overall Equipment Effectiveness (OEE) method. OEE is a method used to measure and maximize plant effectiveness based on factors of availability rate, performance rate and quality rate (Wahyu et al., 2024). The availability rate (AR) is the level of operational effectiveness or ratio that describes the utilization of time available for WWTP operation. The performance rate (PR) is a ratio that describes the ability of the wastewater plant to produce treated water quantity according to design. The water quality rate (QR) is a ratio that describes the WWTP ability to produce water quality that meet standard. The calculation of OEE index presented at Equation 7, 8, 9, and 10.

$$\text{OEE Index (\%)} = \mathrm{AR}(\%)x\ \mathrm{PR}(\%)\ \mathrm{x}\ \mathrm{QR}(\%) \ \ldots (7)$$

$$\mathrm{AR} = \frac{\text{WWTP operation time}}{\text{projected operation time}} \mathrm{x}100\% \ \ldots (8)$$

$$\mathrm{PR} = \frac{\text{Influent quantity}}{\text{design capacity of WWTP}}\ \mathrm{x}\ 100\% \ \ldots (9)$$

$$\mathrm{QR} = \frac{\Sigma\text{parameters meet standard}}{\Sigma\text{parameters x total of sampling}}\ \mathrm{x}\ 100\% \ \ldots (10)$$

Each factor of OEE has a standard value according to the world-class standard recommended by the Japan Institute of Plant Maintenance (JIPM) (Pandey, 2019). World-class standards recommended by JIPM the OEE index is 85%, if the index is about 60% that the plant is considered normal, but there are some factors that need to be improved. While if the OEE index is less than 40%, communal WWTPs can be improved after solving the problems according to observed variables in the study location.

Community Characteristic

The community characteristics in decentralized wastewater service areas were studied to assess the demographic conditions, understand community participation, and examine perspectives on wastewater management. This study used participatory observation, interviews, questionnaires, and group discussions. Data measurement includes 25 variables of community characteristics (Figure 5). The assessment used the Guttman scale, descriptive rating scale, interval rating scale, and Likert scale. The number of respondents were 80-100 at each study location. In this study, the validity and reliability tests of the questionnaire were conducted on 60 respondents in some locations. The validity test applied correlation analysis of Bivariate Pearson or the Pearson Product Moment. The reliability test of the questionnaire applied the Cronbach's Alpha formula.

The explanatory factor analysis method was used to describe the relationship between different observed community variables with principal components (PC) or factors. To apply Principal Component Analysis (PCA) method properly, the data should go through a structured set of preprocessing steps. The steps include exploring variable data, standardizing the data, measurement of sampling adequacy use the Kaiser-Meyer-Olkin (KMO) test, and correlation between variables use Bartlett's test of Sphericity. Observed variables were extracted into correlated variables and identified data patterns for each variable by PCA method and factor rotation by the varimax method. The total of PC determined by eigen value (>1), scree plot (70-80%), and the total amount of variability of original variables. The output of factor analysis is the rotated component matrix and component score coefficient. The validation of PCA community characteristic applies cross–validation/split-sample method that the dataset divides into two random halves then analysis involves variance (scree plot and eigen values) and loading scores.

Implementation Readiness

In this study, a new approach for the management of wastewater and faecal sludge at a communal system, or SIPALT could be implemented for safe sanitation access. The independent variables that influence the implementation of SIPALT was identified from a literature study and stakeholder discussion. The selected variables were analyzed by relative important index method and the confidence interval test. The prediction of SIPALT implementation readiness was analyzed by

cluster analysis (CA) and multiple discriminant analysis (MDA) method to provide a statistical classification. The analysis of implementation of SIPALT considers multivariate problems influenced by several variables with varying correlation values (Khakoonabadi et al., 2021). The Method of CA and MDA can analyze the statistical laws of multiple objects and multiple indicators, which can be a valuable tool for identifying factors in water systems (Liu et al., 2021).

The CA method was applied to determine technology priority in SIPALT, using an agglomerative technique, average linkage, and proximity analysis based on Euclidean distance. The analysis involved an algorithm to measure the Euclidean distance between 18 variables that influence technology selection as shown in Table 3. The CA process comprised the following stages:

- The matrix consists of 18 dominant factors in the X direction and 15 technology options in the Y direction
- A reference SIPALT was determined based on the maximum or minimum values of the dominant variables.
- The priority index calculated based on capability of technology development (Zj) and the magnitude of effort required (Ej).
- Calculation of mathematical distance between points (i.e., from one point to another) for each variable.
- Capability index was analysed using the Euclidean distance method, applying the formula $Zj = \sqrt{(x^2 + y^2)}$.
- Comparation of technology options based on Zj to the target capacity (Zmax) represents Ej required to reach the target.

To know the classification of implementation readiness in each study location, the MDA method was applied. The MDA is an empirical method based on observed factors over a large number of aspects (Luca et al., 2023). In this study, the MDA method distinguishes between three occurring classifications that are established based on the known previous clusters determined by CA. The discriminant function for each classification based on measurement of 18 dominant independent variables as in Table 3. The requirements for discriminant analysis are the independent variable has a large influence on the dependent variable and there is no very extreme data (outliers). The method for constructing the discriminant function employs a simultaneous approach or stepwise discriminant analysis has stages are as follows:

- Testing the assumption of multivariate normal distribution which is assessed using Skewness and Kurtosis tests.
- Testing the equality of group means to examine the similarity of variable by Wilks's Lambda value.
- Testing the assumption of homogeneity of variance-covariance matrices using Box's M test.
- Testing the significance level and Wilks's Lambda at each stage, using a simultaneous estimation method.
- Testing for correlation among independent variables; the presence of strong correlation indicates multicollinearity.
- Testing the significance level and eigen values to measure the strength of the relationship regarding the discriminant results, or the magnitude of variability in the dependent variable explained by the independent variables.
- Objects are classified by accounting for the interrelationships among dependent variables of implementation readiness and identifying the independent variables that make significant contributions.
- The prediction of implementation readiness in 15 study locations analyzed based on the three discriminant functions and territorial map.

The linear combination of six variables in Table 3 (P4, P5, E2, E4, C1, and C3) is obtained to distinguish three classifications of SIPALT implementation readiness. The classifications of dependent variables to assess implementation readiness of SIPALT are technical factor (MKT), management and environmental factors (MKL), and social economic factor (MKSE). These classification analysis align by Brzusek et al. (2022) that multi-criteria analysis for readiness to implement wastewater systems can be used to verify economic, socio-economic, technical and institutional sustainability.

Table 3. The independent variables observed in study locations

No.	Symbol	Variable Description	Unit/rating scale of assessment
MKT			
1.	P1	Existing user of communal WWTP	Number of user
2.	P2	Volume of wastewater treatment	m^3
3.	P3	Influent quality index of communal WWTP	1)>157: heavily polluted, 2)127-157 moderately polluted, 3)98-127 lightly polluted, 4) <98 included domestic wastewater quality
4.	P4	Effluent quality index of communal WWTP	1)>105: heavily polluted, 2) (85-107) moderately polluted, 3)65-85 lightly polluted, 4) <65 meet effluent standard
5.	P5	Consumption of clean water	L/capita/day
6.	P6	Type of communal treatment process	1) conventional system, effluent discharge to the river (eg. naerobic Baffled Reactor) 2) biofilm system, effluent discharge to the river 3) biofilm system, effluent for reuse (eg.Biofilter Reactor and Constructed Wetland)
7.	P7	Wastewater detention time	Hour
8.	P8	Solid/faecal sludge loading	kg total solid /m^2 year
9.	P9	Effectiveness of communal WWTP	OEE value

Table 3. The independent variables observed in study locations (cont.)

No.	Symbol	Variable Description	Unit/rating scale of assessment
MKL			
1.	E1	OPI of communal plant	1)<5 heavily polluted, 2) 5-10 moderately polluted, 3) >10 lightly polluted
2.	E2	OPI of individual plant	
3.	E3	Total Individual plant in planning area	Potential desluding from individual plant
4.	E4	Influence of land use condition	
5.	E5	Condition of individual plant	
MKSE			1)very poor, 2)poor, 3)fair, 4)good, 5)very good
1.	C1	Community participation	
2.	C2	Community motivation	
3.	C3	Community perception	
4.	C4	Management problem solving	

Source: processed by author

The prediction of implementation readiness of SIPALT is based on classification of MKT, MKL and MKSE. The classification is categorized as ready for implementation (SI), less ready for implementation (KSI), and not ready for implementation (TSI). The discriminant functions at each classification have variables contribution as shown in Table 3 (MKT influenced by P4 and P5, MKL influenced by E2 and E4, MKSE influenced by C1 and C3) as described at Equation 11 to 16.

$$\mathrm{MKT}-1=1,298-3,498\mathrm{P4}+0,105\mathrm{P5}\ldots(11)$$
$$\mathrm{MKT}-2=-6,979+1,523\mathrm{P4}+0,041\mathrm{P5}\ldots(12)$$
$$\mathrm{MKL}-1=-41,562+39,309\mathrm{E2}-6,274\mathrm{E4}\ldots(13)$$
$$\mathrm{MKL}-2=-10,212+1,519\mathrm{E2}+2,760\mathrm{E4}\ldots(14)$$
$$\mathrm{MKSE}-1=-20,486+3,401\mathrm{C1}+2,269\mathrm{C3}\ldots15)$$
$$\mathrm{MKSE}-2=-0,731-1,303\mathrm{C1}+1,559\mathrm{C3}\ldots(16)$$

Evaluation of the classification was carried out by discriminant function accuracy method. The accuracy analysis is based on the apparent error rate (APER) criteria, hit ratio (percentage of object groups that can be predicted correctly), and chance criteria (Cr). If the group sizes are unequal, the maximum chance criteria (Cmax) can be used and accurate classification shows the hit ratio > Cmax > Cr. In addition, the accuracy of discriminant function was tested by cross validation method and leave-one-out cross validation that a discriminant function that can predict height has a value of more than 50%.

RESULTS AND DISCUSSION

The environmental degradation of Citarum Watershed occured due to regular desludging from decentralized wastewater treatment plants and improper faecal sludge disposal. In this study, improvement of decentralized wastewater in Citarum settlement area considers the treatment process of wastewater and faecal sludge, management, and environment. The improvement of decentralized wastewater by SIPALT approach could be a part of safe close loop faecal sludge management in settlement area that consists of faecal flow, wastewater treatment, sludge handling, and resource recovery. The classifications of SIPALT readiness implementation in existing communal WWTP were analysed according to their plant performance, community characteristics, and environmental factors.

Performance of Communal Treatment Plant

The communal WWTP for service of 30-100 households in study locations have technology such as anaerobic baffled reactor (ABR), biofilter, anaerobic digester (AD) or their combination (Table 4). In some study locations, the communal plant completed a further treatment, such as constructed wetland. The scheme of existing flow of wastewater and faecal sludge which has no proper faecal sludge disposal at one of study locations shown in Figure 2. The condition of limited faecal sludge disposal because the community organization faced difficulties to access to and no availability centralized sludge treatment plant as well as the surrounding user of individual or on-site wastewater system.

The cluster analysis (CA) results technology priority in SIPALT based on index of development pattern and development measure which have an average of 6,97 and 0,75 with each critical distance of 9,27 and 1,01. The priority technology had been determined by CA method had been decided also based on focus group discussion of stakeholders which the selected technology as shown in Table 4. The selected sludge treatment will influence composition or volume liquid fraction or reject water which are highly dependent also on the process conditions (Mucha & Mikosz, 2021). The plant adapted to local condition, the system of wastewater and faecal sludge treatment is easy to operate or maintain and low cost (Verma et al., 2020). While sludge amount and quality are highly impacted by several parameters, including the treatment technology employed, treatment efficiency, and the volume and content of influent (Paramita et al., 2021).

The index of influent and effluent from communal wastewater system were analyzed by WWQI method to describe condition of series data refers to measure parameters and national standard. The index based on data of physical parameters (pH, TSS) and chemical parameters (BOD, COD, ammonia, oil and grease). The influent index of communal wastewater shows mostly moderate pollution category (index of 127-157) that are influenced by sanitation behavior, water supply, sewer pipe maintenance or land use influence to communal facility.

Table 4. Existing communal WWTP and plan of faecal sludge treatment

No.	Location	Communal WWTP	Capacity (HH)	Sludge treatment
1	L1	AB, SSCW	50	SSCW
2	L2	ABR, VB	30	SDB+CC
3	L3	ABR, AB	50	SSCW
4	L4	A2B	50	SSCW
5	L5	AD, AB, SSCW	50	CC
6	L6	AD, AB	50	SSCW
7	L7	AB	100	SDB+CW
8	L8	AD, ABR	50	CT +CW
9	L9	ABR -AF	50	SSCW
10	L10	AB	100	SDB+ CC
11	L11	AB, SSCW	30	SSCW
12	L12	AD, ABR	50	CC
13	L13	AB	100	SSCW
14	L14	ABR-AF	50	CC
15	L15	ABR-AF	50	CC

Source: processed by author

Note: HH (households), ABR (Anaerobic Baffled Reactor), VB (Vermibiofilter), AB (Anaerobic Biofilter), A2B (Anaerobic and Aerobic Biofilter), AD (Anaerobic Digester), ABR-AF(ABR-upflow filter), CT (combined treatment), CC (Co-composting with organic waste), SSCW (Sub Surface Constructed Wetland), SDB (Sludge Drying Bed).

The effluent index of communal WWTP at some locations has category of moderate pollution (index 85-105 in L2, L3, L4, L8, L10). Some locations have category of light pollution (L1, L5, L6, and L11) according to some observed effluent parameters meet standard. In these locations, the communal WWTP are intended for water reuse which have a further anaerobic treatment such as subsurface constructed wetland therefore effluent quality is better than other locations. The macrophyte in constructed wetland can filter pollutant but the its management influenced by seasonal change or maintain plant growth as mentioned also by researchers (Pincam & Jampeetong, 2020). The effluent of communal WWTP is categorized light or moderate pollution category. The effluent category will increase to the non-pollution category if community can keep good treatment process, routine emptying faecal sludge, and no flooding or any disturbance influence the WWTP facility. This condition was stated by McConville et al. (2019) that social understanding and treatment process are important factors in improving wastewater systems in rural areas.

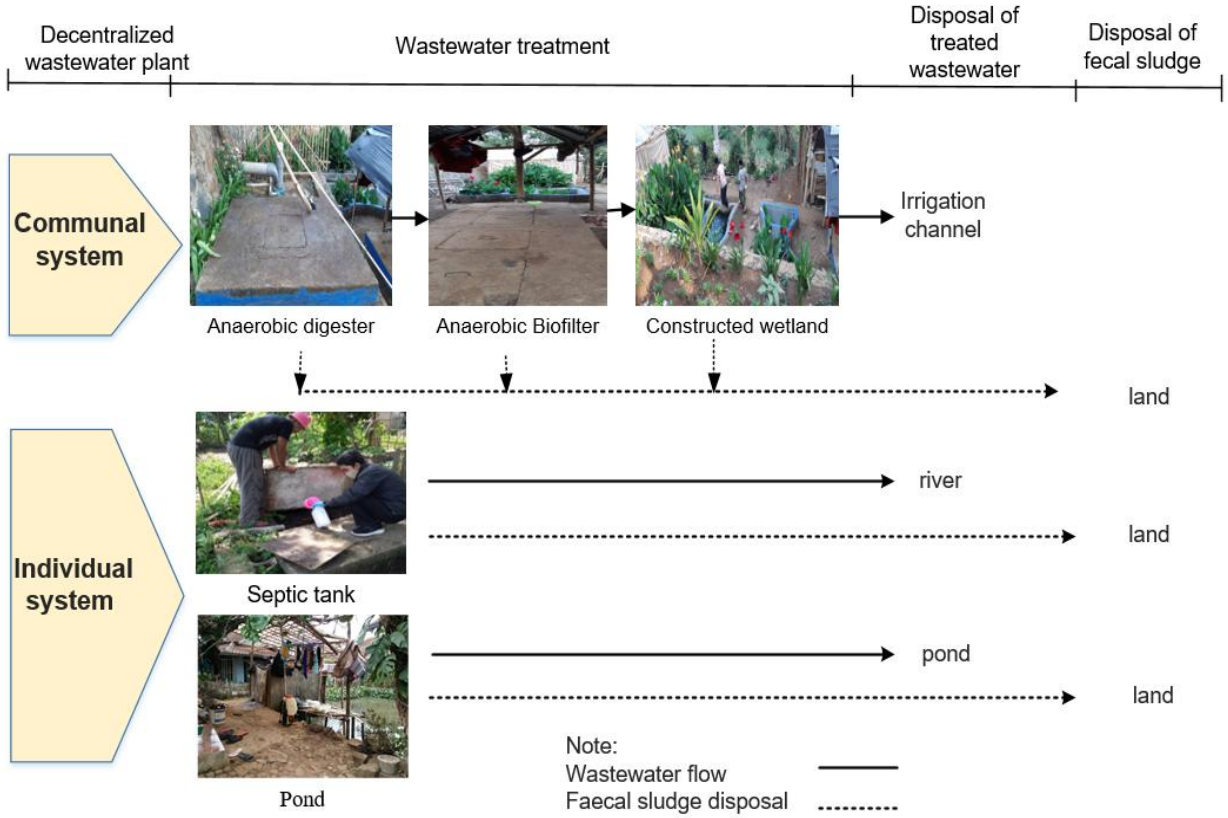


Figure 2. The scheme of wastewater and faecal sludge flow in a study location

Source: processed by author

The performance of wastewater treatment is influenced by the routine emptying of faecal sludge produced as a result of treatment process during a certain period. The faecal sludge characteristics studied include the quality of faecal sludge and the accumulation of faecal sludge per year from communal WWTP. The result of faecal sludge quality testing provides an overview of the local characteristics of faecal sludge in communal WWTP described by value of OPI and CI (Figure 3).

Most of OPI of faecal sludge in communal WWTP indicate low pollution category whereas CI indicate high pollution. The faecal sludge quality will determine faecal sludge treatment, therefore the maintenance of communal WWTP and pratreatment of faecal sludge treatment should be high attention in SIPALT development. Some variations in sludge quality are large due to differences in types of collection systems and sanitation behavior, and are also influenced by soil infiltration to some facilities, and the duration of sludge storage (Tayler, 2018).

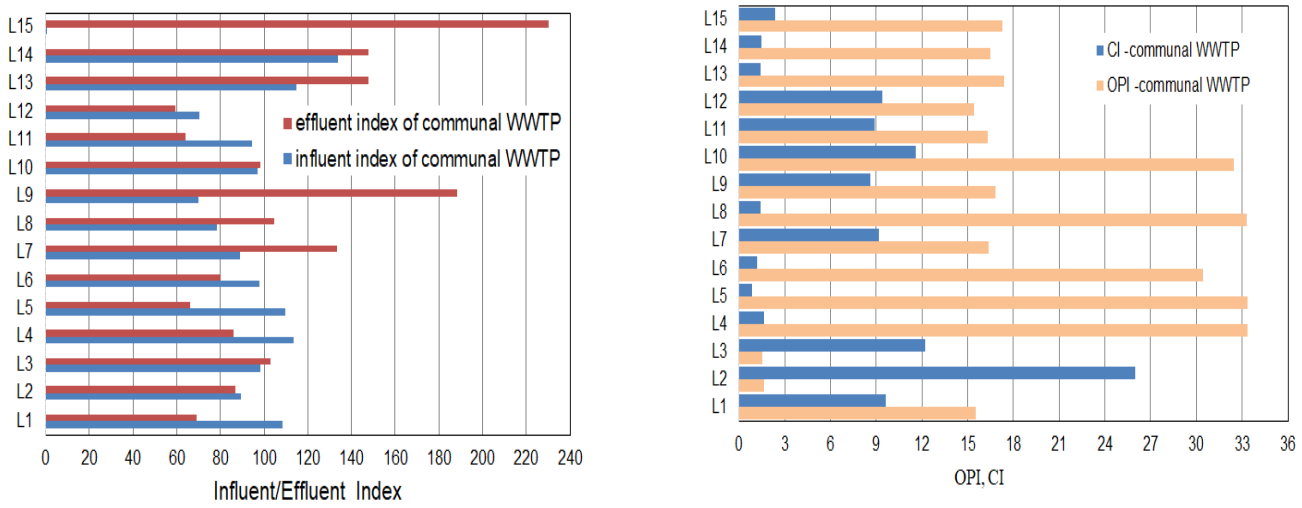


Figure 3. The index of wastewater and faecal sludge in communal WWTP
Source: processed by author

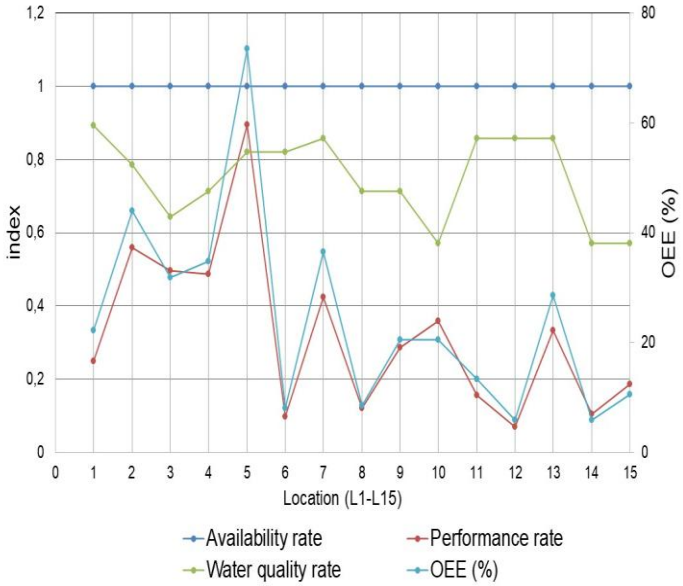


Figure 4. The OEE of communal WWTP
Source: processed by author

The effectiveness of communal wastewater system cannot be separated from the analysis of operation unit as a work tool that produces treated water. The OEE value for communal wastewater treatment in each study location shown in Figure 4. The OEE value based on factor of performance rate that most of the communal plant are operated by community below wastewater treatment capacity design, except in L5 and L7 operated as treatment design capacity. The communal WWTP have total of OEE value about or more than 40% in location of L2, L5, L7, and L13 which show has good potential for system improvement and developing on-site faecal sludge management by community.

In terms of water quality factor, the communal plant's ability has varied value (40-60%) according to parameters comply with effluent standard. The rate of water quality in L1, L7, L11, L12, and L13 has a higher value than other locations as in Figure 4. This condition could indicate that maintenance of wastewater plant is one of the important factor in ensuring the treated wastewater quality complies the standard. The communal plants in L3, L4, and L6 have low OEE values (< 40%) because treatment capacity and some parameters of effluent quality can not meet standard. The communal WWTP in these locations can be improved to SIPALT with considering also observed factors according to category of implementation readiness.

Community Characteristic

The analysis of community characteristic by factor extraction of PCA method results 20 dominant variables. These variables will influence the improvement of communal WWTP in study location. The factor analysis index of community variables based on loading factor (significant level α = 0,05), eigen value, and coefficient score can be seen in Figure 5. The variables index of participation in management of wastewater system (2,45) that include maintain the facility was identified as a main loading factor influence SIPALT implementation. The community understanding about wastewater or faecal sludge impact, type of treatment, operation and maintenance. The understanding of water supply encompasses knowledge of facilities, environmental impact, clean water source, water quality, water continuity, purpose of water use, and volume of water use. The community perception of sanitation has index of 1,67-1,78 that would influence participation in programs related to willingness of involvement and responsibility in management (Werdhani & Karuniasa, 2020). The better understanding of the variables of impacts of wastewater or faecal sludge (1,67-1,73) could be have greater community's motivation to manage the facilities. The community characteristic influences the development of a decentralized wastewater system (Capps et al., 2020) and its success implementation that will determine the quality of work, operation and maintenance of infrastructure, community partnerships and participation (Hidayat et al., 2023).

In study location, sanitation activities are greatly influenced by clean water (0,54-0,72), especially in Bandung Regency on which is a water prone area and groundwater crisis area (Yusuf et al., 2018).The sustainability of clean water supply affects the wastewater treatment process and is influenced by community understanding. Meanwhile the education variables (1.68) will influence the improvement of sanitation but in study location, last education is more than 60% from junior high school. The community understanding will be influenced by education level thus it determines a positive attitude or behavior which cares the environment (Retnowati & Istiana, 2019). The results of validating PCA of community characteristic indicate that the contribution variables (eigen value >1) have scree plot more than 75%. Therefore the contributed variables of community characterisitc can explain almost all the variability from observed aspect.

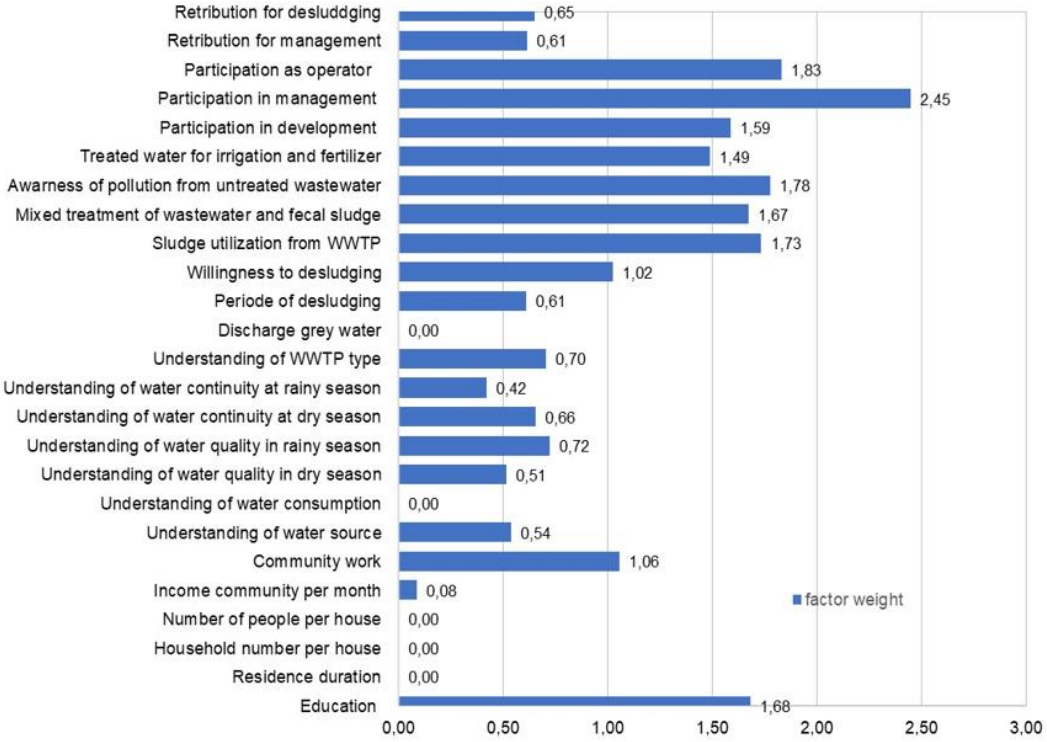


Figure 5. Factor analysis index of community variables
Source: processed by author

The Readiness of SIPALT Implementation

The improvement of communal wastewater existing or new development of SIPALT is a strategy to fulfill minimum service standards of sanitation according to Public Work Ministry Regulation nomor 13 year 2023, increasing save sanitation access in rural area or all urban area. The SIPALT development could support sustainability of SANIMAS program in area with access limited to centralized faecal sludge management. Meanwhile, the implementation of SIPALT with a local community organization had managed communal wastewater plant requires measurement and assessment of multi-aspect readiness. The technology has been selected meet the criteria of an ease of operation and maintenance which rely on the human resource and financial strength of an service area of communal treatment. The analysis of implementation readiness is important because it can minimize the level of failure, difficulties or risks (Subiyakto, 2018).

In this study, the analysis of SIPALT implementation readiness applies discriminant analysis based on 18 variables (Table 3) represent aspect of technical, management, environment, and social economic. According to MDA method, the readiness of SIPALT implementation is influenced by variables classified terms of readiness of communal wastewater system or technical factor (named as MKT), environmental factor (MKL), and community factor (MKSE). In term of MKT, the most important variables are effluent wastewater quality and clean water consumption will influence the implementation readiness of SIPALT. In terms of MKL that the implementation readiness distinguished by most important variables are faecal sludge index and land use condition. In terms of MKSE that the readiness of implementation is measured by variable of community participation and perceptions in the use of treated wastewater and solids for agriculture.

The prediction of implementation readiness of SIPALT has categories with symbol of 0, 1, or 2 by discriminant function of MKT, MKL, and MKSE obtained by stepwise modes are shown in Table 5. The coordinate of MKT, MKL, and MKSE create a territorial map that determines category of 0, 1, or 2 of existing communal wastewater plant. The discriminant functions have achieve accuracy based on hit ratio, each of 86%, 60%, and 80%. The function of MKT, MKL, MKSE have Cr/Cmax of 33%, 33%, 33% and APER of 86%, 73%, and 87% respectively. The validation test applied cross-validation analysis by

the leave-one-out method result the accuracy values of MKT, MKL, and MKSE has 86,7%, 60,0%, and 73,3% respectively. The function for readiness implementation can measure in case of type of communal treatment plant and environmental condition in study location. The prediction accuracy based on six dominant variables based on technical, environmental, and socio-economic aspect. Meanwhile, determination a strategy and program for SIPALT implementation should consider observed variables in Table 3 involves as differentiators in the classification of implementation readiness category.

In Table 5 shows six locations have category of ready for implementation (symbol 2) of MKT that they have good maintenance of communal plant. The other locations categorized as not ready implementation of MKT thus the communal wastewater system need to be improved for some variables, such as wastewater treatment process or water supply facility. Meanwhile the study location categorized water crisis area therefore clean water source should be maintained by ensuring catchment areas and community activities do not pollute water sources. While some locations in Table 5 have categorized as not ready for implementation in terms of MKL that need improvement environmental aspect. The variable impacted to faecal sludge quality is condition of individual wastewater plants (mainly near communal plant that will a part of SIPALT) and land use condition including housing development influence the performance of wastewater facility.

In Table 5, there is a study location (L7) categorized ready for implementation according to MKL and MKSE (symbol of 2). The location has good influence from spatial planning and high community participation and good perceptions of wastewater and faecal sludge treatment and management. In terms MKL, the location has condition of low pollution category of faecal sludge and spatial condition variables that influence management, including location characteristics as in research by Starkl et al. (2022), such as proximity to discharge points, topography, and infrastructure availability. The implementation of SIPALT in L7 should consider also improvement of other variables in Table 3. Meanwhile there are two locations in Table 5 (L1, L5) have ready implementation in terms of MKT, MKL, and MKSE that will influence strategy and program for SIPALT development. The good condition of community characteristic in these locations can support improving wastewater management and controlling pollution.

Table 5. Score of discriminant function and category of SIPALT implementation readiness

No	Score		Cate-	Score		Cate-	Score		Cate-
	MKT-1	MKT-2	gory	MKL-1	MKL-2	gory	MKSE-1	MKSE-2	gory
L1	-0, 767	0, 854	2	2, 462	0, 697	2	2, 192	0, 293	2
L2	0, 624	-1, 485	1	-2, 098	0, 877	0	-1, 208	1, 596	1
L3	1, 677	-1, 077	1	0, 378	-0, 980	1	-0, 076	-1, 266	0
L4	2, 731	-0, 669	1	-1, 024	-2, 109	1	-0, 076	-1, 266	1
L5	1, 340	1, 670	2	2, 462	0, 697	2	2, 192	0, 293	2
L6	-3, 928	-0, 371	0	-2, 015	0, 949	0	-3, 477	0, 037	0
L7	-0, 796	0, 870	2	-5, 358	0, 194	0	2, 194	0, 293	2
L8	2, 702	-0, 653	1	-5, 238	3, 201	0	-3, 476	0, 037	1
L9	0, 602	-1, 473	1	1, 036	0, 441	1	-9, 146	-0, 219	0
L10	-0, 796	0, 870	2	1, 036	0, 441	1	-3, 476	0, 037	1
L11	-2, 896	0, 050	1	-12, 062	2, 938	0	2, 194	0, 293	2
L12	0, 602	-1, 473	2	-5, 788	0, 178	0	-9, 146	-0, 219	1
L13	10, 400	-0, 536	1	-11, 632	2, 954	0	2, 194	0, 293	2
L14	-2, 896	0, 050	2	-5, 385	0, 194	0	-9, 146	-0, 219	1
L15	6, 200	-2, 176	1	-5, 385	0, 194	0	-9, 146	-0, 219	1

Source: processed by author
Note: symbol categories: ready for implementation (SI/symbol 2), less ready for implementation (KSI/symbol 1) and not ready for implementation (TSI/symbol 0)

The SIPALT is as decentralized wastewater system in terms of faecal sludge practice with technology development and management integrated with communal wastewater management, consists of a chain of WWTP systems and a series of interrelated activities in operation and maintenance followed by financing options and potential income. The best SIPALT management cost reduction option could be applied in location categorized as ready for implementation, such in L1 or L5. The treated water from communal wastewater plant that can be reused, there is also the potential for biogas, slurry, and compost from faecal sludge processing in L5 thus allowing managers to earn additional maintenance costs.

The development of wastewater plant with the resource recovery concept will contribute to socio-economic conditions, especially related to the benefits to be obtained, as well as growing community participation (Marleni & Raspati, 2020). In a study location, SIPALT pilot scale has been applied in location L7 which has a prediction of ready implementation for category of MKT and MKSE. The selection of L7 because of some supports for upgrading of treatment process in communal WWTP. Challenges in L7 were faced in term of MKL that need efforts to improve faecal sludge quality and land use condition, also some in environmental variables. The SIPALT management in L7 requires the involvement of community and related stakeholders or local government in every component of management.

Integrated wastewater and sludge systems are new in developing countries (Silva et al., 2018) and have a potential to be implemented because a number of existing communal WWTPs are not optimal or predicted to be underutilized in the future (Narayana, 2020). The SIPALT approach had been implemented in some rural's India which apply strategy and programs, such as raising awareness of appropriate collection systems, the government regulating financing options for rural management, and preparing human resources through capacity building to improve sludge service capabilities (WaterAid India, 2017). The success key of sustainable and long-term wastewater treatment is synergy between all stakeholders, including local governments, the central government, the private sector, the public, and local communities (Gumilangsari et al., 2021). The sanitation service chain of SIPALT have different treatment plant and potential financing sources. The wastewater management cannot be separated from good governance principles to address the public need for save sanitation access.

CONCLUSION

The communal wastewater systems mainly in rural or peri urban area that have not yet covered or have limited access to centralized faecal sludge facility could be improved by approach of integrated communal wastewater and on-site faecal sludge system (SIPALT). The SIPALT consists of faecal flow, wastewater treatment, on-site sludge treatment, and resource recovery that considers minimum treatment in accordance with intended end-use and characteristic of community.

In location study, the influent quality index of communal WWTP show mostly moderate pollution category that are influenced by factor of sanitation behavior, water supply, maintenance, or land use. The effluent quality index of communal WWTP in some locations have category of moderate pollution and light pollution. Most of OPI of faecal sludge in communal WWTP indicate low pollution category whereas CI indicate high pollution. OEE index in some communal WWTP has a value of over 40% thus have potential for SIPALT implementation.

The assessment of implementation readiness of SIPALT based on classification of variables of communal wastewater system, environmental, and community characteristic. Most study locations are categorized as less or not ready for SIPALT implementation. Therefore the strategy and program should be applied for variable improvement, mainly effluent quality, clean water supply, faecal sludge quality, land use condition, community participation or perceptions regarding wastewater and faecal sludge management.

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ABBREVIATIONS

AD (Anaerobic Digester), APER (Apparent Error Rate), BOD (Biochemical Oxygen Demand), CA (Cluster Analysis), COD (Chemical Oxygen Demand), CI (Contaminant Index), FSTP (Faecal Sludge Treatment Plant), FSM (Faecal Sludge Management), KSI (category of less ready for implementation), JIPM (Japan Institute of Plant Maintenance), MDA (Multiple Discriminant Analysis), MKT (Technical Factor), MKL (Environmental Factor), MKSE (Community Factor), OEE (Overall equipment effectiveness), OPI (Organic Pollution Index), PC (Principal Components), PCA (Principal Component Analysis), WWTP (Wastewater Treatment Plant), SANIMAS (Community-Based Sanitation), SIPALT (Communal WWTP integrated with on-site faecal sludge treatment system), SI (category of ready for implementation), TSI (category of not ready for implementation), TSS (Total Suspended Solid), WWQI (Wastewater Quality Index), SI (category of ready for implementation).

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