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Waste processing techniques at the landfill site using the material flow analysis method

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ABSTRACT

BACKGROUND AND OBJECTIVES: Waste remains an issue in tandem with the development of the local community. The quantity of waste that is stockpiled in the landfill impacts the amount of leachate, resulting in emissions and reduced landfill capacity. The main challenge for its management is choosing the most cost-effective method to minimize leachate and emissions and increase the amount of waste that is stockpiled, resulting in a longer service life of the landfill. This study aimed to select the treatment at a landfill site.

METHODS: Field observations and sampling of waste composition were carried out at the Klaten Regency. Waste composition sampling was carried out over several years. Material flow analysis was used to calculate the amount of leachate, emissions, and waste in the landfills. The effectiveness and benefits of the treatment scenarios were compared.

FINDINGS: The waste consists of 55 per cent organic, 24 per cent plastic, 10 per cent paper, 3 per cent wood, 2 per cent cloth, 1 per cent glass, 1 per cent metal, and 4 per cent others. The processing scenarios were determined based on this composition. Four prospective scenarios were identified: 1) waste processing with composting; 2) composting and reuse, reduction, and recycling; 3) waste to energy; and 4) the combined process of scenarios 1 – 3. All treatments carried out can reduce leachate by 5.09 – 14.32 per cent, emissions of 11.31 – 44.48 per cent, waste 14.13 – 65.97 tons/day in the landfill, and can extend the service life of the landfill by 3 – 14 years.

CONCLUSION: Material flow analysis was used to calculate the waste processing, emission rate, and leachate production from the four processing scenarios. The reduction of leachate and emission was affected by the treatment used. Combined processing (scenario 2 or 4) can reduce leachate and emissions and extend service life. The selected processing alternative must also consider the benefit-cost ratio. Scenarios (2) and (4) have a benefit-cost ratio of more than 1, which means that the processing is feasible to implement. Scenario 4 has a higher investment cost; so, the scenario that can be applied to the Troketon landfill is scenario 2 with a small investment cost, capable of reducing polluters, extending the landfill's service life to more than 4 years, and a benefit-cost ratio of more than 1.

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49

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10

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3

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INTRODUCTION

The increase in population and the development of the economic level influence people's behavior, lifestyle, and consumption patterns (Laohalidanond et al., 2015). These behavioral changes also increase waste generation (Audina, 2018) and demand for management facilities. Municipal solid waste management (MSWM) includes collection, transport, processing, material and energy recovery, and final disposal (Martinez et al., 2012). The need for a sustainable form to maintain a clean environment and public health (Hoque and Ur, 2020). Solid waste management (SWM) in Indonesia still relies on the municipal solid waste landfill (MSWLF) as the estuary. The available MSWLF also becomes longer, less inadequate, and incurs high operational costs. Infrastructure development, specifically MSWM is slow. Out of approximately 69% of waste that goes to landfills, 10% has not been processed. Law No. 18/2008 concerning waste management mandated the use of a sanitary landfill system for waste disposal, in reality, many cities and districts continue to apply the open dumping technique (Lokahita et al., 2019). The Ministry of Environment and Forestry (2021) reported that 67.58% of waste has been managed by reduction and handling, while the remaining 32.42% was left unmanaged. Approximately 15.78% of the collected solid waste was reduced from the sources. SWM from the source is performed by reuse, reduction, and recycling. 51.8% of it is managed through storage, collection, transportation, and final disposal. Solid waste entering MSWLF comes from households, such as food or biodegradable solid, paper, plastic, and diapers (Kiddee et al., 2014). The limited land available for MSWLF affects its management, specifically disposal services. 60-70% of refuse could be transported and disposed of at MSWLF, while the remainder is improperly processed or managed (Effendy et al., 2012). The physical, economic, social, political, and institutional factors that influence SWM in different cities/regencies in developing countries necessitate a SWM system designed for their needs. Social, economic, and technological developments have also affected the increase in SWM (Al-Dailami et al., 2022). Developed countries have implemented the zero waste concept, which aims to change SWM practices, including household waste management, in a more sustainable direction due to their concern for environmental hygiene and health. The concept includes solid waste prevention, recycling, recovery of all resources from solid waste, and behavior change (Cole et al., 2014). Waste in Indonesia is managed by transporting it into the MSWLF. This process produces leachate and landfill exhaust gases that can pollute the environment (Ratnawati et al., 2019). Leachate can contaminate surface water and groundwater (Mukama et al., 2016), whereas landfill gas can pollute the air and increase the potential for global warming (Sauve and Acker, 2020). The emissions from MSWM account for approximately 5% of all greenhouse gas emissions (Towa et al., 2019). Klaten Regency, Central Java, is one of Indonesia's districts with SWM problems. The MSWLF Troketon method is a controlled landfill system. Waste management in a regency is not optimal. The amount of accumulated solid waste reduces the lifetime MSWLF (Ratnawati et al., 2022). Gao et al. (2017) describes the integration of system dynamics (SD) and material flow analysis (MFA) into the circular economy theory to build a comprehensive framework based on regional economies. Ratnawati et al. (2022) reported landfill calculations using compost processing with predictions of waste generation. Markic et al. (2019) used material flow analysis for planning, based on separate collection and recycling. From previous studies, the novelty of this study is the material flow analysis used to compare the results of the effluent produced from the landfill using 4 scenarios. The 4 scenarios are scenario 1 using compost, scenario 2 using a combination of compost and reuse, reduce, recycle, scenario 3 process waste into energy, and scenario 4 combining compost, 3R, and waste to energy. This study aims to examine and compare several waste processing scenarios that can extend the service life of MSWLF by predicting the output produced in the form of leachate, emissions, and refuse stockpiled in the landfill using the MFA method. This study was conducted in MSWLF Troketon, Klaten Regency, in 2022.

MATERIALS AND METHODS

This study was conducted in Klaten Regency, Central Java Province, Indonesia (Fig. 1) from February 2020 to May 2022. This location was selected based on the waste management problem at the MSWLF. Fig. 2 presents a flowchart of the study stages. The results obtained could be recommended for improving waste management at the final site in a regency.

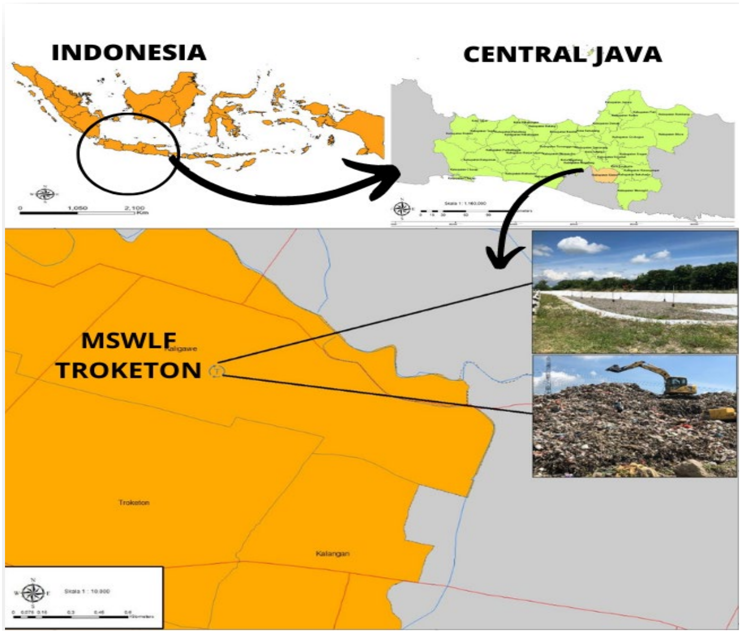


Fig. 1: Geographic location of the study area in Klaten Regency, Indonesia

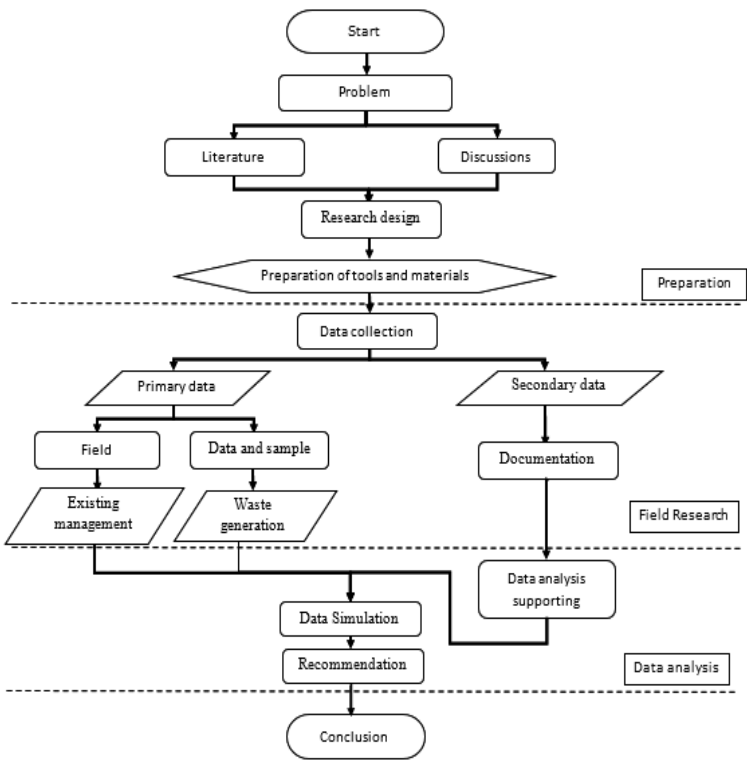


Fig. 2: Flow diagram for the overall methodology

Sampling and waste composition

Waste sampling was conducted following the Indonesian National Standard (SNI) 19 – 3964 – 1994 regarding procedures for collecting and analyzing samples of the generation and composition of MSW. This study was performed in March and November 2020, March 2021, and April 2022. Random sampling of waste from trucks entering MSWLF was used, and a minimum of 3 trucks were collected. The waste taken is approximately 35-40 kg of waste/truck. It was obtained at random, then weighed up to 100 kg. Furthermore, the waste was sorted according to its type and weighed. Weight and volume measurements were performed based for each type of waste (Owusu-Nimo et al., 2019). The samples were separated into eight main categories: food waste, plastics, rubber, paper, textiles, non-combustible materials, wood, and other materials (Charkhestani and Kebria, 2022).

Material flow analysis

The material flow analysis (MFA) method is used to determine the flow of waste and the products produced in the management model scenario (Markic et al., 2019). The flow started from the solid waste entering the MSWLF to the resulting output through the processing process. The model was created by processing the waste data entering the MSWLF, indicating that it can describe the flow of refuse products as well as the number of emissions and leachate produced. The output of the processed waste (Out_i) is obtained by calculating the incoming waste (In_i) multiplied by the percentage of processed waste (R_i) was calculated using Eq. 1.

$$\sum Out_i = \sum In_i \times R_i \quad (1)$$

Landfill life (Remaining life)

The useful life of a landfill can be calculated from the amount of stockpiled waste. The useful life calculation determines the extent to which a landfill can be used. Waste processing in MSWLF can extend the service life by reducing the amount of solid waste that enters landfills using Eqs. 2 and 3 (Ratnawati et al., 2022).

$$\sum \text{waste with land cover} = \sum \text{waste to landfill} + (\sum \text{waste to landfill} \times \text{cover soil}) \quad (2)$$

$$\text{Remaining life} = \frac{\text{Capacity landfill}}{\text{waste with land cover}} \quad (3)$$

Carbon emission

Waste management produces carbon emissions from landfilling, processing waste into compost, and waste processing by burning. The unusable carbon emissions in the landfills were calculated using Eqs. 4 and 5 and Table 1 (IPCC, 2019).

$$Lo = DDOC_m \bullet F \bullet \frac{16}{12} \quad (4)$$

Where:

L_o = CH_4 gas potential produced (Gg CH_4)

$DDOC_m$ = mass of degraded and decomposed organic carbon (kg)

F = CH_4 gas fraction from landfill gas produced.

$\frac{16}{12}$ = molecular weight ratio CH_4/C

$$DDOC_m = W \bullet DOC \bullet DOC_f \bullet MCF \quad (5)$$

Where:

$DDOC_m$ = degraded and decomposed organic carbon (kg)

W = mass of wet waste removed (kg)

DOC = degraded organic carbon fraction

DOC_f = decomposed organic carbon fraction

MCF = CH_4 correction factor on aerobic decomposition

Where:

Table 1: Value of DOC, DOC_F, MCF, and F from waste type (Towprayoon et al., 2019)

Waste type	DOC	DOCf	MCF	F
Organic	0.15	0.7	0.5	0.5
Paper	0.4	0.5	0.5	0.5
Wood	0.43	0.5	0.5	0.5
Textile	0.24	0.5	0.5	0.5

Table 2: Waste generation in Klaten Regency from various sectors

Sector	Waste generation	
Total waste generation in Klaten Regency	378.15	Tons/day
Total waste transported to MSWLF	94.24	Tons/day
MSW generation rate	0.3	kg/individual/day
Domestic waste generation	1.3-1.5	kg/house/day
Waste generation from hotels, hospitals, Islamic boarding schools	0.0957	Tons/day
Market and commercial waste generation	7.57	Tons/day

Leachat.e generation

Leachate is permeated water produced from solid waste heaps as well as being a solvent for harmful dissolved pollutants, especially organic solutes. Leachate can contaminate both soil and water. Proper processing is required to avoid leachate and environmental pollution. Equation 6 is the quantity of leachate generated (Youcai, 2018).

$$Q = I\left(C_1 A_1 - C_2 A_2\right)/1000 \quad (6)$$

Where:
Q = quantity of leachate generation, m^3/d
I = rainfall, mm / d
C_1 = leaching coefficient coefficient of operating landfill area (0.6)
C_2 = leaching coefficient coefficient of covered landfill area (0.6)
A_1 = operationg landfill area, m^2
A_2 = covered landfill area, m^2

Cost analysis

Waste management involves investment and operational costs. Operational costs consist of employee wages, fuel cost for heavy equipment, and waste-processing cost. Profit is derived from the sale of fertilizers, recycled goods, and generated energy. The benefit-cost ratio (BCR) was used to determine the feasibility of investment. A BCR ≥ 1 implies that the investment is feasible, but it indicates infeasibility when it is < 1, using Eqs. 7 and 8 (Chaerul and Rahayu, 2019).

Operational cost = employee wage + fuel cost heavy equipment + waste processing cost (7)

$$\text{BCR} = \frac{profit}{Operational\ cost} \quad (8)$$

RESULTS AND DISCUSSION

Description of the study area and context

Klaten Regency covers an area of 65,556 ha (655.56 km^2) or 2.014% of Central Java Province (3,254,412 ha). Its territory covers all administrative regions, consisting of 26 sub-districts, 391 villages, and 10 sub-districts, with a population of 1,260,506 people based on 2020 data. Rainfall affects the degradation process of organic waste in landfills and impacts the amount of leachate produced. The regency has a tropical climate with alternating rainy and dry seasons, temperatures between 28-30 degrees Celsius, average wind speeds ranging from 20-25 km/hour, and the highest rainfall occurs in February 2020, which is 492 mm with 16 rainy days. The lowest rainfall was in July 2020, as much as 1 mm in 1 rainy day. The amount of waste produced in an area is influenced by the activities in the location, population, and economic growth sectors, such as education, tourism, health, and industry. There are 2,420 schools and colleges, 125 tourist attractions, 407 restaurants, 21 markets, 440 offices, 203 health facilities, 3,285 supermarkets/minimarkets/retails, 35,382 industries, 52 hotels, 5 Islamic boarding schools, and 56 settlements. These facilities are sources of waste in Klaten Regency and are generated from residents' domestic activities.

Description of waste management in Klaten Regency

Waste management system includes storage, collection, transfer, transportation, and final disposal. Solid waste services have reached all subdistricts in the Klaten Regency. The Communal housing facilities in this region are shelters made of concrete/brick masonry. They are often found in schools, hospitals, housing, and settlements. There is 207 communal waste disposal ranging in sizes from 3 – 50 m^3 and 18 containers with a volume of 6 m^3 in the regency. Direct individual waste collection in this region is performed using a three-wheeled motorcycle and then transported directly to landfills. Indirect collection was performed using waste carts accommodated at temporary disposal sites. These carts were operated under the management of the village head. In the direct collection system, the generated waste is directly delivered by the source to a temporary communal shelter and then transported to MSWLF using a truck (Jimmyanto et al., 2018). Based on data from the environmental service of Klaten Regency in 2021, an average of 94.24 tons of waste is sent to MSWLF in Klaten Regency every day.

Waste generation and composition at the study site

The waste generated in Klaten Regency originates from domestic and commercial activities. Domestic waste comes from residents, while commercial waste comes from markets and supermarkets. Table 2 shows the waste generated by various sectors in the regency. The amount of waste entering the MSWLF will continue to increase in 2016 - 2021, as shown in Fig. 3, and it is necessary to conduct processing to extend the service life. Alternative processing is determined by determining the composition of the waste generated at MSWLF. The waste from housing/settlements consists of plastic packaging, paper, organic materials (in the form of vegetable/food scraps), diapers, cloth, wood, glass, rubber, and others that are not included, whereas commercial waste is in the form of organic materials, plastic, paper, and wood (Fig. 4). The waste produced is predominantly organic; therefore, alternative processing can be performed in the form of composting. The treatment of waste, specifically organic material in compost, has not been widely conducted in the regency, as has occured in various cities in developing countries (Thushari et al., 2020). Reuse, Reduce, and Recycle (3R) alternative processing to reduce waste. The amount of waste that enters MSWLF is reduced by scavenging activities (Sahwan et al., 2004). Scavengers pick up inorganic waste such as paper, plastic, metal, glass, and rubber, which still have economic value to be used directly or sold to the industry as raw materials (Sarja, 2020; Tarigan et al., 2016). Solid wastes such as paper, plastic, and metal waste can be recycled into crafts. Paper waste can be recycled into art papers (Sahwan and Wahyono, 2002). Plastic waste is sold to the industry as plastic raw materials (Permatasari and Rahdriawan, 2013) and industrial fuel (Wahyudi et al., 2018). Metal waste such as used food cans can be easily separated from landfills, recycled into items of artistic value, re-melted back into the original material. It can also be used as a cement mixture (Anggraini et al., 2018). The role of scavengers is the key to reducing waste generation (Sasaki et al., 2014). Waste that cannot be processed through composting and 3R can be used as fuel for turbines, producing electrical energy. This process is known as Waste to Energy (WtE).

In Klaten, the quantity of MSW per capita is 0.3 kg/day, and the increase in the generation of Municipal solid waste is about 1.21%. The quantity of MSW per capita in Klaten is close to the quantity of MSW per capita in a rural areas of Yemen. Waste treatment in Sana’a, Yemen using composting and incinerators (Al-Dailami et al., 2022).

Description of waste management at MSWLF Troketon

The waste from the local shelter was transported

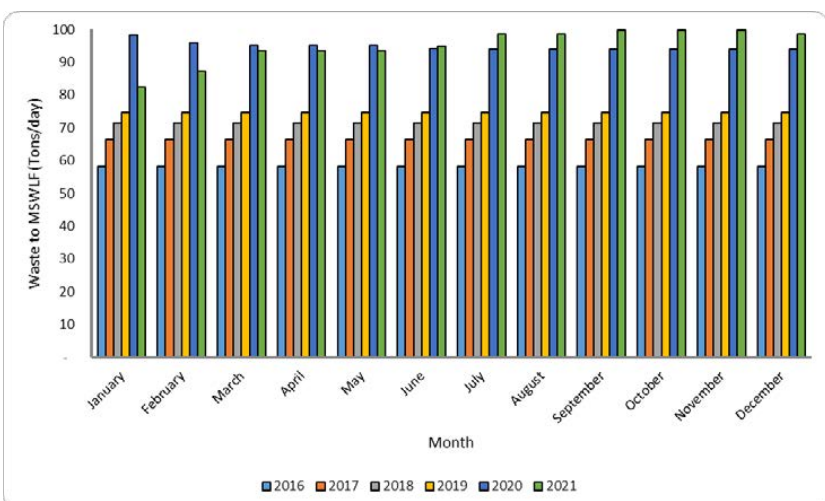


Fig. 3: Amount of waste that goes to MSWLF

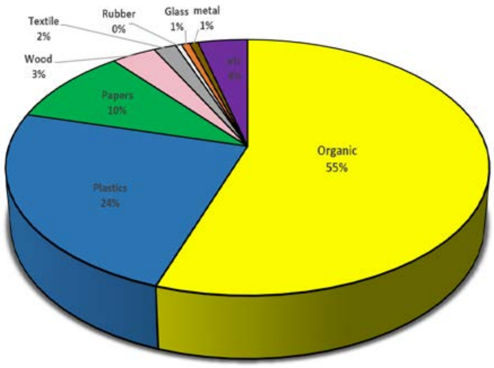


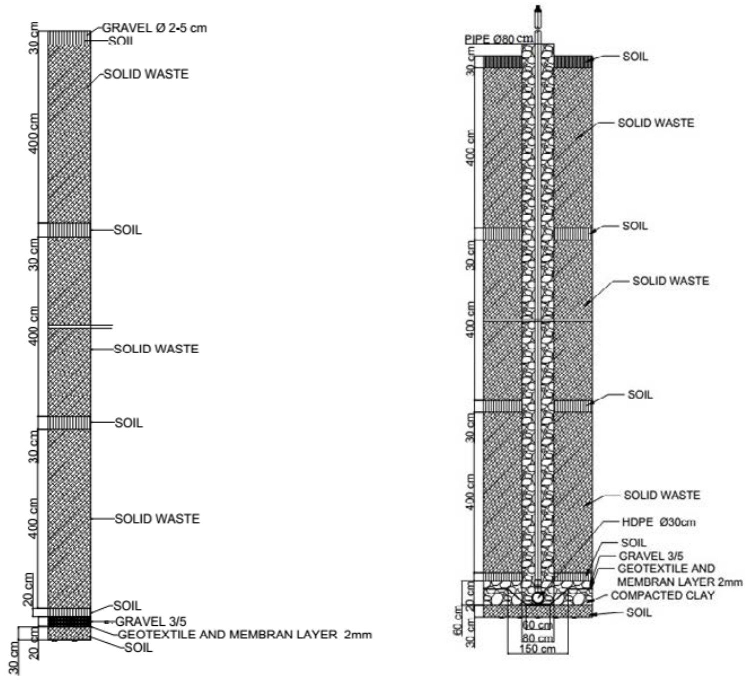
Fig. 4: Waste composition in MSWLF Klaten Regency

to the MSWLF Troketon for disposal at a landfill site. The type of vehicle is adjusted to the volume, location, distance, and ownership, including the tricycle, pick up, dump truck, or arm roll. MSWLF Troketon is located in the Pedan Sub-district. It has an area of approximately 7.08 ha, with 3 built-up zones. The area of zone 1 is 9,914 m^2 and the area of the zone 2 is 8,295 m^2. The total capacity of zones 1 and 2 was 172,986 m^3, of which 73% was used. The capacity of zone 3 is 74,623 m^3 which is used after zones 1 and 2 are filled. The final method for solid waste disposal is controlled landfill. The control landfill method applied in the Troketon landfill is that the solid waste entering the landfill is covered with soil every 3 days. The bottom layer of the landfill functions as a waterproof coating so that leachate does not seep into the soil, which results in the contamination of the soil and groundwater (Fig. 5). Landfill base coating materials are geotextile, and geomembrane can withstand the resulting leachate 477.93 m^3/d. The geomembrane serves as a waterproof layer, and geotextile serves as the wear and reinforcement of the liner.

The minimum thickness of the geomembrane is 1.5 mm and above the geomembrane is layered with a minimum thickness of 4 mm of geotextile. The height of the landfill is 10 m above ground level, with the depth of stockpiling ranging from to 3-5 meters. The embankment at the location of the landfill block with a slope of 45^o. The waste that enters the MSWLF Troketon is weighed on the bridge and then the waste is weighed and sorted based on its organic and inorganic contents. 1.5 - 3 tons of waste has been composted but the implementation is not continuous owing to limited manpower. Inorganic wastes such as plastic, textiles, paper, and metals are picked up by scavengers for recycling, reuse, or sale.

Waste management model at MSWLF

Waste management at the final processing site can be improved by implementing a hierarchy consisting of prevention, reuse, recycling, recovery, and landfill (Wang et al., 2020). This approach has been applied in several attempts to implement sustainable urban solid waste management (Kulkarni, 2020). Efficient segregation and integrated waste management are expected, which can minimize the burden of solid waste disposal on the ground (Abdulredha et al., 2020). Applicable integrated waste treatment consists of reduction, separation, transfer, recycling, recovery, and processing (Seng et al., 2018). Several alternatives for waste management development can be divided into two categories: intensification and extensification. Intensification is performed by reducing composting organic waste, recycling plastic, and processing waste technology into electrical energy (waste to energy). Extensification was conducted by expanding the land at the final processing site (Manurung et al., 2016). Urban solid waste, mainly organic matter, can be composted to preserve soil and reduce waste pollution (Khajuria et al., 2008). Urban waste management consists of compostable (40–60%) and inert materials (30–50%) (Kolekar et al., 2016). During the composting process, 75% compost products, 22% air emissions, and 3% leachate are released (Guo et al., 2019). Recycling is the process of planning, implementing, and controlling the efficient flow of goods and related information from the consumption point to the final processing site. This is where discarded electronic goods are collected and sent to recycling centers for recycling and final processing (Bellien et al., 2012). Waste processing into electrical energy (WtE) is the best solution for energy efficiency and the reduction of greenhouse gas potential (Liu et al., 2017) as well as the amount of stockpiled waste, thereby decreasing operational costs (Laner et al., 2019). The electrical energy produced is approximately 4% (Neehaul et al., 2019). WtE is an environmentally friendly processing technology that reduce waste (Mulyadin et al., 2018). It reduces the potential for global warming but has little economic impact (Maheshi et al., 2015). Landfilling produces methane gas, which can be processed into electricity (Verma et al., 2016) and



(a) (b)

Fig. 5: (a) Solid waste closure at MSWLF; (b) Gas pipeline installation in MSWLF

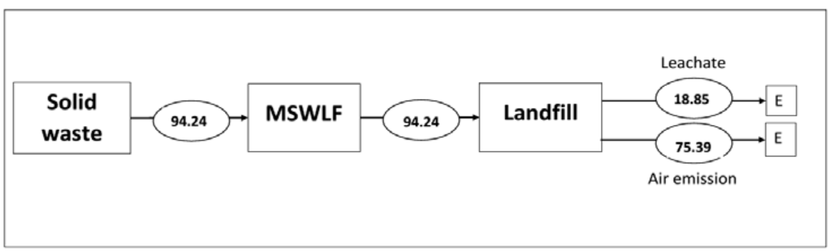


Fig. 6: Flow diagram of existing waste at MSWLF Troketon

has emission percentage of 48.9% (Zhou et al., 2015). Urban waste consisting of organic material is easily biodegradable and has high humidity. The separated organic material was processed into compost (Youcai and Ziyang, 2017). The four management strategies that can be applied in Klaten Regency are waste processing with composting, composting and 3R, WtE, and a combination of compost, 3R, and WtE, which are indicated as scenarios 1, 2, 3, and 4. These scenarios were selected based on the composition of the MSWLF. Degradable, recyclable, and unused wastes can be processed using composting, 3R, and WtE, where they are burned in a reactor to be converted into electrical energy. In the existing waste flow chart, the percentage of leachate produced was 18.85%, whereas the emission is 75.39%, as shown in Fig. 6. Leachate emissions generated from landfill and composting then flown into leachate processing plant. The air emissions generated from landfill can be collected using a piping system.

According to Fig. 7, the treatment with compost (scenario 1) reduced 6.41 % leachate and 21. 86 % of emission from exsisting (Fig. 6). Fig. 8 shows waste processing using compost and 3R (scenario 2) reduced 9.24 % of leachate and 33.17 % greater than scenario 1.

Compared to other types of treatment, WtE (Fig. 9) has an emission reduction value of 11.31% compared to the existing management. The combined treatment (Fig. 10) of composting, 3R, and WtE resulted in emission reduction and leachate values of 44.48% and 14.32% compared to the existing condition. Fig. 10 shows that the combined processing of composting and 3R's use of landfills to store unprocessed waste is significantly less than that of other processing alternatives.

Table 3 shows the current performance of MSWLF Troketon waste management and potential improvement scenarios. According to the table, scenario 4 is better than the others scenarios in terms of environmental and financial benefits. In addition, the processing of scenario 4 produces energy that is utilized. The use of WtE in scenarios 3 and 4 not only produces energy but also requires installation costs and new equipment, as well as operating costs for utility consumption. WtE processing processes that can be used include gasification and combustion processes that require mechanical drying and installation of an initial thermal drying process that requires mechanical drying (Quan et al., 2022). Thermal treatment can be performed by combustion, gasification, or pyrolysis. Waste enters the combustion reactor during the combustion process. The heat generated in the reactor was converted into electricity (Quan et al., 2022). The combustion process produces flue gas and waste from combustion. Waste from combustion during pyrolysis is often called biochar, which can be used

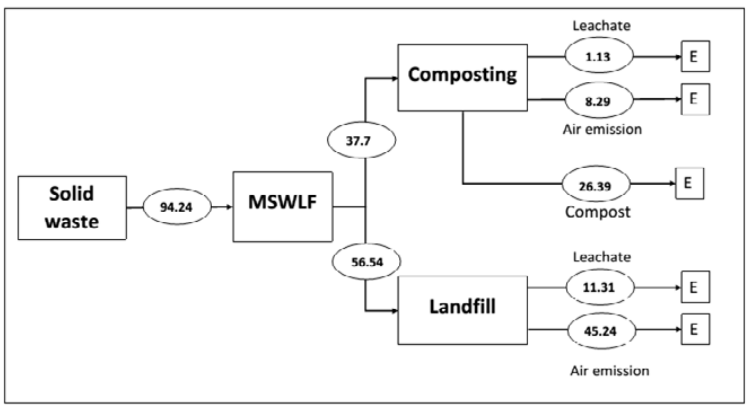


Fig. 7: Flowchart of compost processing (scenario 1)

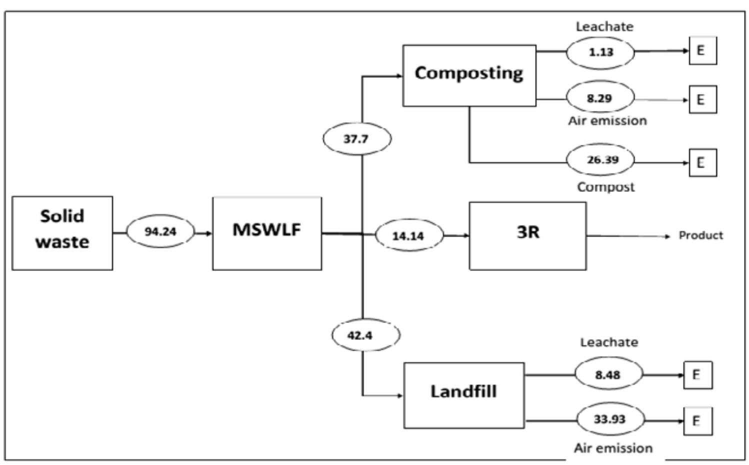


Fig. 8: Flowchart of compost processing and 3R (scenario 2)

for agriculture (Yavari et al., 2022). Scenario 3 and 4 the waste that enters MSWLF is processed into electricity with the characteristics of waste moisture content 47.4% weight, ash content 6.7% weight, volatile matter 45.6% weight and measured low heating value of 8.5 MJ/kg (MPWHRI, 2018). The processing scenarios can also be determined based on the social aspects and aspects of processing technical specifications. Social aspects are related to the effect of processing on the health of the surrounding community as well as the impact on the community's economy. Technical specifications are also used to determine the equipment capacity and processing efficiency.

Based on Table 3 scenario 1 has the lowest investment cost compared to other scenarios. Scenario 1 is able to extend the life of landfills longer and reduce pollutant greater than scenario 3. In addition, the benefit cost ratio of scenario 1 is was greater than that of scenario 3. The processing of scenario 3 produced more energy than scenarios 1 and 2. Scenario 2 is able to extend the landfill's service life by 2 years longer than scenario 3 and has a higher benefit-cost ratio than scenario 3. Scenario 4, compared to other scenarios is able to reduce polluters more, has the longest landfill life, is able to produce energy, and has the largest benefit-cost ratio but a high investment. Scenario four no can be implemented in Klaten Regency, because waste processing is also influenced by financing. Landfill financing in Klaten Regency comes from the Regional Expenditure Budget (REB); thus, financing for a year comes from the budget and submissions of the previous year and is based on the approval of the Regional House of Representatives. Scenario 4 requires a large investment so that it cannot be met by the regional budget. Scenario 4 cannot be directly implemented in Klaten Regency. Financial aid from other parties must be prepared to implement this scenario. Scenario 2 was chosen because the resulting benefit-cost ratio has also reached 1.022%.

CONCLUSION

The increasing amount of solid waste entering the MSWLF, the lack of segregation by type, and the technological constraints of waste processing in landfills are the primary issues with the management at the landfill site. The proposed solution is to sort and process waste at the MSWLF. There are four scenarios: waste processing with composting (scenario 1), composting and 3R (reuse, reduce, recycle) (scenario 2), waste to energy (WtE) (scenario 3), and combination of composting, 3R, and WtE (scenario 4). Scenario (1) can reduce leachate by 6.41%, and emissions by 21.86%. Scenario (2) can reduce leachate by 9.24%, and emissions by 33.71%. Scenario (3) can reduce leachate by 5.09%, and emission by 11.31%. Scenario (4) can reduce leachate by 14.32%, and emissions by 44.48%. Scenario 1 can extend the service life of the landfill to 2 years longer than the existing. Scenario 2 can extend the service life of the landfill to 3 years longer than existing. Scenario 3 can extend the service life of the landfill by 1 years longer than existing. Scenario 4 can extend the service life of the landfill by 12 years longer than existing. Processing scenarios 3 and 4 can generate energy but also incure a high investment cost. The results of scenario 4 (combination of composting,

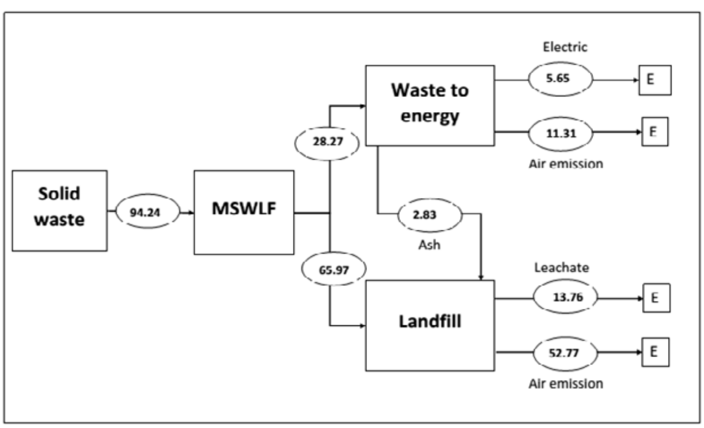


Fig. 9: Flowchart of WtE processing (scenario 3)

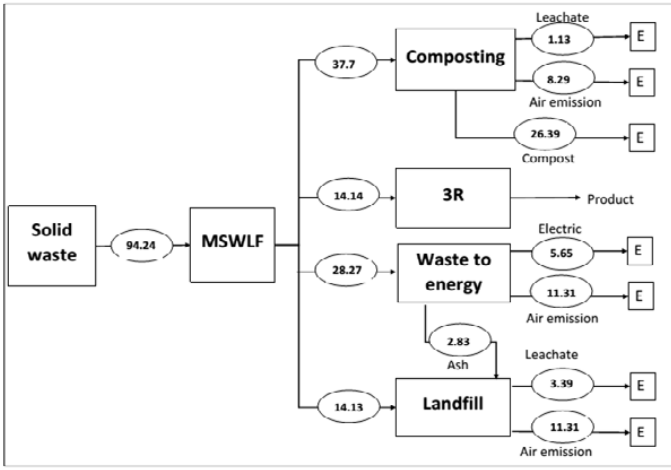


Fig. 10: Flowchart of combined processing (scenario 4)

Table 3: Performance of the existing waste management at MSWLF Troketon and improvement of the management scenario

No.	Criteria	Existing	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	The volume of waste at MSWLF (tonnes/year)	34,397.6	34,397.6	34,397.6	34,397.6	34,397.6
2	Volume of waste treated (tonnes/year)	0	13,760.5	18,921.6	10,318.55	29,240.15
3	Landfill life (years)	2	4	5	3	14
4	Carbon emissions (tons CO_2 eq/ton waste)	56.76	41.46	32.72	51.84	26.6
5	Energy gained (MJ/year)	0	0	0	13,183	13,183
6	Additional investment (IDR)	0	60,000,000	90,000,000	793,000,000	853,000,000
7	Processing cost (IDR/month)	1,245,428	1,275,349	1,375,349	1,295,428	1,335,349
8	Added value-profit (IDR/month)	-	1,023,981	1,406,218	938,823	2,345,041
9	BCR	0	0.803	1.022	0.725	1.756

3R, and WtE) were the best among all the scenarios. This is indicated by the high pollutant reduction, long landfill life, large benefit-cost ratio, and energy generation. Scenario 4 cannot be applied directly to the Troketon landfill because of the high investment, so preparation and assistance from other parties are needed to make it happen. From this study, the selected scenario that can be applied to the Troketon landfill is scenario 2, which is a combination of compost and 3R. Material flow analysis can be used to analyze the four processing scenarios clearly, so that leachate flow, emissions, and stockpiled solids can be seen. The study gives insight into environmental aspects (reducing leachate and emission, and service life landfills), and economic aspect (additional investment, processing cost, value profit, and benefit-cost ratio). It is necessary to study processing scenarios based on social aspects and technical specifications to obtain comprehensive results for determining waste management in MSWLF.

AUTHOR CONTRIBUTIONS

A. Beata Ratnawati performed the sampling, data analysis, interpreted the data and results, and prepared the manuscript text. B. Mohamad Yani performed energy analyzed and played a role in coordinated the substance and publication of the research results. C. S. Suprihatin controlled the calculation result for the processing scenario. D. Hartrisari Hardjomidjojo control the interpretation of the model.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this paper. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication, falsification, double publication, submission, and redundancy have been completely addressed by the authors.

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ABBREVIATIONS

A_1	Operating landfill area, m^2
A_2	Covered landfill area, m^2
BCR	Benefit – cost ratio
C_1	Leaching coefficient of operating landfill area
C_2	Leaching coefficient of covered landfill area
cm	centimeter
CH_4	Methane
CO_2	Carbon Dioxide
DDOCm	mass of degraded and decomposed organic carbon
DOC	degraded organic carbon fraction
DOC_f	decomposed organic carbon fraction
E	Emission
Eq	Equation
Eqs	Equations
eq	Equivalent
F	CH_4 gas fraction from landfill gas produced
Gg	Gigagram
ha	Hectares
I	Rainfall, mm/d
IDR	Indonesian rupiah
IDR/month	Indonesian rupiah/month
In_i	The incoming waste
kg	Kilogram
kg/day	Kilogram/ day
kg/individual/day	Kilogram/ individual/ day
km/hour	Kilometers/ hour
kg/house/day	Kilogram/ house/ day
L_o	CH_4 gas potential produced (Gg CH_4)
m^2	Square meter
m^3	Cubic meter
m^3/d	Cubic meter / day
mm	Millimeter
MCF	CH_4 correction factor on aerobic decomposition
MFA	Material Flow Analysis
MJ/kg	Mega Joules /kilogram
MJ/year	Mega Joules /year
MSW	Municipal Solid Waste
MSWLF	Municipal Solid Waste Landfill
MSWM	Municipal solid waste management
Out_i	The output of waste processed
Q	Quantity of leachate generation, m^3/d
R_i	Percentage of processed waste
REB	Regional expenditure budget
SD	System Dynamic
SNI	Indonesia National Standard
SWM	Solid waste management
W	Mass of wet waste removed (kg)
WtE	Waste to energy
°	Degrees
ø	Diameter
∑	Total
%	Percent
3R	Reuse, reduce, recycle
16/12	Molecular weight ratio CH_4/ C

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