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MULTI-CRITERIA ANALYSIS FOR SELECTING SOLID WASTE MANAGEMENT CONCEPT CASE STUDY: RURAL AREAS IN SENTANI LAKE REGION, JAYAPURA

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ABSTRACT

Aim: This study aims to identify, develop, and determine the most suitable concept of solid waste management to be applied in Ifale Village, Yobeh Village, Putali Village, Atamali Village, and Asei Besar Village. Until now, the application of solid waste management system in Jayapura is still far from what people expected since it has been unable to serve the communities who live in rural areas on the islands around Sentani Lake. As a result, 12,554.38 liters/day of solid waste generated by the community in these regions is left untreated. **Methodology and Results:** The study is using the Analytic Hierarchy Process (AHP) method. The AHP calculations show that the idea of handling solid waste in an integrated treatment facility—following the initial sorting on the household scale—has the highest priority weight (2.05) compared to the other alternatives. Hence, it has been chosen as the best solid waste management concept that can be applied to the study sites. Based on the results as well, the main criteria to be considered include the environmental aspects, social aspects, and technical aspects with each weighing value of 0.534, 0.186, and 0.147, respectively. **Conclution, significans and impact study:** The sub-criteria with the highest priorities to be considered in making the decision are the soil pollution (due to produced leachate), air pollution (potentially in the form of stench and gas emissions), the transmission of disease vectors, public participation, and the operational convenience.

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1. INTRODUCTION

People do various activities in their daily lives, and inevitably, waste is produced as the side effect of these activities (Hariastuti, 2013). If not properly handled, it can cause negative impacts on the environment and human health (Laurent, et al, 2014). The primary problem concerning solid waste management in a city is the annually increasing rate of solid waste generation. It remains an unresolved issue since there is no adequate waste management system (Borongan and Okumura, 2010). In line with that, Al-Khatib et al. (2010) said that waste management is one of the most challenging problems faced by developing countries as a result of serious pollution caused by the increasing amount of waste from year to year. Besides, the waste problem has been an issue of interest to the global community as well, in accordance with the population growth and changes in consumption patterns of the community (Marshall and Farahbakhsh, 2013). This issue resembles the current situation in Jayapura where the existing solid waste management system is still far from what was expected. Even though Jayapura District has a solid waste system plan, it has not been properly implemented on the field. There are no evident measures to treat the municipal solid waste generated from this district, whereas another complication is catching up: the growing population and urban consumptive lifestyle have started to spread to the indigenous people, leading to the higher amount and wider range of solid waste characteristics.

The location of Jayapura District—between the stretch of Cyclops Mountains Nature Reserve and Lake Sentani - also has its own challenges concerning the solid waste problems. A lot of indigenous people of Jayapura District are still living on the islands in Sentani Lake, so it is very difficult for them to afford any waste infrastructure. As a result, the waste generated there is simply dumped or burned in their yards and often are directly discharged into Lake Sentani. In addition, the common solid waste management schemes implemented in various places cannot be established in this area because no system can be optimally applied to all areas (Highfill and McAsey, 1997 and White et al., 1999 in Chen et al., 2005). Thus, a study to devise a solid waste management system that can be developed in rural areas on islands in Lake Sentani is required. Several determinants taken into account include the social aspects - such as the desire of the community and their local wisdom to manage the waste—as well as technical and non-technical aspects of solid waste management. It corresponds with what Chen et al. (2005) said, that the characteristics of the region (e.g. the condition of the region, customs, as well as culture and local

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wisdom) are crucial in determining the solid waste management system; this is especially true for small islands. Thereby, an effective and efficient solid waste management can be designed.

The multi-criteria analysis is a method that has been widely used in the process of decision making in both fields of social sciences and engineering (Saaty and Vargas, 2001 in Abba *et al*., 2013). Some the methode to analysis are Composite Performance Index (CPI), Bayes Method, Metode Analytical Hierrarchy Process (AHP). One of the multi-criteria analysis techniques widely used to analyse a limited number of alternatives is the Analytic Hierarchy Process or AHP (Saaty, 1980 in Contreras et al., 2008). AHP method is a framework to achieve effective decision making on complex problems (solving these issues in smaller certain parts) by simplifying and speeding up the judgment process. The steps include arranging parts or variables in a hierarchical order, giving a numerical value on the subjective judgment of the importance of each variable, synthesizing these considerations to determine the variables with the highest priority, and act to influence the outcome of the situation (Bhushan and Rai, 2004 in Sener et al., 2010).

This study intends to produce the best alternative of solid waste management concept that is suitable and can be applied to the rural area on the islands in Sentani Lake, Jayapura District. It aims to find out the solid waste management model preferred by the community in accordance with the local wisdom, examine all the feasible schemes of solid waste management then sort the most compatible plan.

2. RESEARCH METHODOLOGY

This paper discusses the determination of solid waste management concept at rural areas on the islands in Sentani Lake (Ifale Village, Yobeh Village, Putali/Ebung Fa Village, Atamali/Khameyaka Village, and Asei Besar Village) by considering the technical and non-technical aspects of solid waste management as determinants in the decision making. The study site is shown in Figure 1.
In order to make decisions in this study, the stages that must be passed are:

1. Preliminary Study

   Preliminary studies were conducted to understand the theory of solid waste management system in general, the concept of solid waste management in a regional scale, technical and non-technical aspects of solid waste management, local wisdoms of Sentani tribe, the literature on the implementation of a survey using a questionnaire and how to design an

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effective questionnaire, as well as the use of AHP method and similar studies that have been done before.

2. Primary Data Collection

   Primary data collection consists of:

   - Calculation of waste generation and composition using the calculation method based on SNI 19-3964-1995, represent Sampling and Measuring Methods of Examples of Urban Solid waste generated and Composition
   - Field observations,
   - Creation and dissemination of the questionnaire.

3. Secondary Data Collection

   Secondary data refers to the supporting data gathered from literature studies and reports on the condition of the study area.

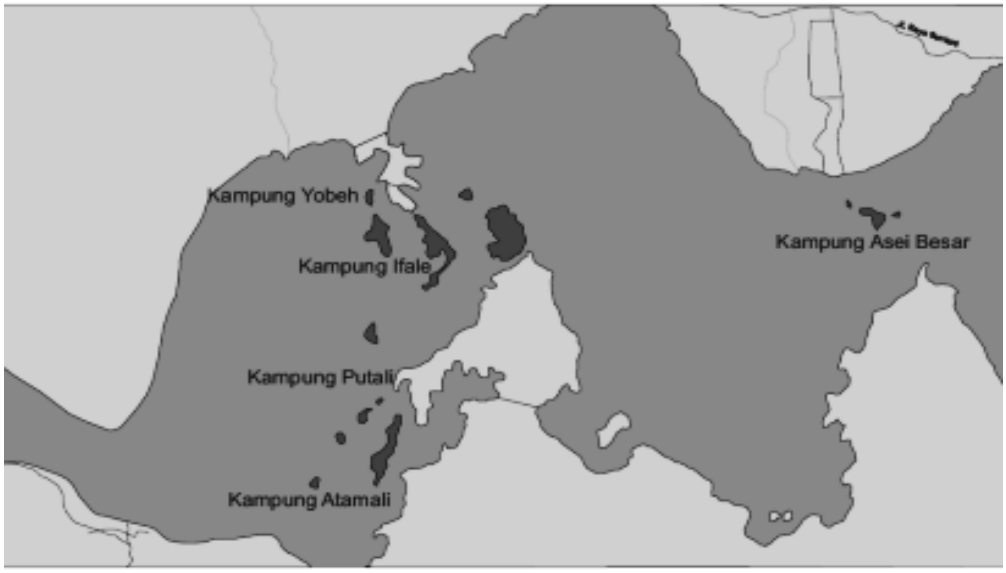

Figure 1 Map of the study site

4. Evaluation of the Existing Solid Waste Management Existing in Study Sites

   The evaluation was conducted using the descriptive analysis method which aims to elaborate the existing condition of the solid waste management as well as the community's preference and local wisdom concerning waste management based on the distribution frequency of

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respondents and questionnaire responses. The steps in this descriptive analysis are (Sugiyono, 2013):

- Editing—to correct or to check the data from the questionnaire.
- Coding—the provision of sign/symbol/code for each data included in the same category. Signs can be a number or letter.
- Tabulating—the meticulous grouping of similar answers, followed by the calculation of how many events are included in the category.
- Data presentation—where the results of the data tabulation are collected and displayed in the form of tables and graphs to make it easier to understand.
- The Development of Alternatives, Criteria, and Sub-criteria of the Solid Waste Management Concept

5. The development of solid waste management alternative concept comprised of the following stages:
   - Identification of solid waste management alternatives based on the evaluation of the existing condition as well as the community's preference and local wisdom about solid waste management,
   - Development of solid waste management concept that can be applied to the study site.

   The criteria used in this study include technical aspects, social aspects, environmental aspects, institutional aspects, and economic aspects. These criteria were determined based on the aspects of solid waste management listed in SNI 19-2454-2002 and previous researches. As for the sub-criteria, they were drawn according to the results of corresponding studies and the checklist containing the research needs and improvements based on the respondents' feedbacks (Safitri, 2012).
6. Assessment and Determination of Solid Waste Management Concept

   At this stage, the Analytic Hierarchy Process (AHP) method was used to determine the best scheme of solid waste management for the study site among the previously identified alternatives. This assessment was conducted by dividing the 50 respondents into groups of local government, academics, community, and informal sector. The number of respondents was calculated using the purposive sampling technique based on the consideration that the selected person or group acts as decision makers—dealing or directly involved in the solid waste management issue. The person or groups who can provide valuable information and

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deliberation in the decision-making process were also taken into account (Safitri, 2012). The AHP method consists of two stages (Saaty, 2004):

- Structuring is to arrange the flow of decision-making based on two main components; The first factor is the purpose of the AHP (to obtain an effective and efficient waste management concept that can be developed in the study sites) and the variables used (social aspects including the community's preference and local wisdom of waste management as well as the institutional aspects), while the second component is the alternatives of solid waste management that presumably can fulfil the purpose of the AHP.
- Assessment is the scoring or weighing stage of the variables, sub-variables, and alternatives. It can be either direct assessment, verbal assessment, or visual assessment.

7. Conclusions and Recommendations

   The conclusion is the answer to the purpose of this study, while the recommendation is the outcome resulted from this study based on the assessment and determination of the optimum waste management scheme for the study site.

3. RESULTS AND DISCUSSION

Ifale Village, Yobeh Village, Putali Village, Atamali Village, and Asei Besar Village with a population of 6,193 residents, have an average value of the total solid waste generation based on field measurements of 2.03 liters/person/day. The most dominant types of waste are food scraps, paper, and plastic. The number of solid waste generation per day in this location is 12,554.38 liters/day. Based on the calculations, the projected amount of solid waste generated in 2024 (10 years ahead) and 2034 (20 years later) are equal to 19,683.94 liters/day and 30,862.34 liters/day, respectively. The local community will continue to burn, bury, dump the garbage in the nearest waste containers, or directly dispose solid waste into the waters of Sentani Lake each day if no management system is established in the region. The data of solid waste generation and composition in Ifale Village, Yobeh Village, Putali Village, Atamali Village, and Asei Besar Village are shown in Table 1 and Table 2.

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Table 1 Solid waste generated in Ifale Village, Yobeh Village, Putali Village, Atamali Village, and Asei Besar Village

Village	Population	Average Solid Waste Generated (kg/person/day)	Density (kg/liters)	Average Solid Waste Generated (l/person/day)	Solid Waste Generated (l/day)	Projection of Solid Waste Generated (l/day)	
						(10 Years)	(20 Years)
Ifale	1,306	0.114	0.05	2.28	2,983.29	4,677.49	7,333.81
Putali	1,071	0.095	0.05	1.78	1,901.20	2,980.88	4,673.70
Atamali	743	0.119	0.05	2.18	1,619.51	2,539.22	2,539.22
Yobeh	2,634	0.106	0.06	1.90	5,000.48	7,840.23	12,292.66
Asei Besar	439	0.113	0.06	2.00	877.28	1,375.48	2,156.61

Table 2 Solid waste composition in Ifale Village, Yobeh Village, Putali Village, Atamali Village and Asei Besar Village

Solid Waste Composition	Ifale		Putali		Atamali		Yobeh		Asei Besar	
	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%
Food Scraps	5.28	56.11	2.4	32.3	4.1	48.2	2.9	37.9	3.4	40.0
Paper	0.83	9.40	1.4	19.3	0.8	9.3	1.1	15.2	1.3	15.5
Wood	0.40	4.17	0.6	7.8	0.3	3.1	0.7	9.2	0.8	9.8
Cloth	0.04	0.40	0.6	8.5	0.1	1.7	0.1	1.1	0.2	1.6
Rubber	0.05	0.48	0.1	0.7	0.4	3.3	0.1	0.7	0.0	0.4
Leather	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plastic	1.96	21.01	1.6	21.8	1.9	21.9	1.8	23.9	1.7	19.3
Metal	0.14	1.43	0.4	5.8	0.2	1.8	0.3	4.5	0.6	7.2
Glass	0.69	7.01	0.3	3.2	0.8	10.5	0.6	7.3	0.6	6.0
Others	0.00	0.00	0.1	0.7	0.0	0.0	0.0	0.2	0.0	0.1
Total	9.38	100	7.3	100	8.6	100	7.6	100	8.6	100

Based on the indigenous customs in the study sites, there are some local wisdom developed in terms of solid waste management, i.e. (1) the village's cleaning program; (2) the daily collection of food scraps to be used as animal feeds for pigs, dogs, and fish; (3) the verbal/unwritten rule throughout generations saying that people have to maintain the cleanliness of Sentani Lake and

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should not throw garbage in its water body because it is the source of almost every activity of the local community (such as bathing, washing, and drinking/cooking).

Based on the survey results of the community's preference concerning the solid waste management, the majority of the community in the study area (73%) opts for the individual solid waste handling (directly on their sources in a household scale), while the local government and the community are responsible for the solid waste management process. The local government through DKPP of Jayapura District acts more as a provider of solid waste management facilities and as a partner in the waste processing, whereas the community is responsible for carrying out the solid waste handling through existing community groups such as Youth, PKK, and so forth. Figure 2 depicts the percentage of each preference regarding solid waste management system at the study site.

Figure 2 The percentage of community's preferences regarding the solid waste management system at the study site

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Table 3 Criteria and sub-criteria used in the determination of solid waste management concept

Technical Aspects	Social Aspects	Environmental Aspects	Institutional Aspects	Economic Aspects
Conformity with spatial plan (T1)	Public desire in solid waste management (S1)	Spread of disease vectors (L1)	Availability of the institutions (K1)	Low/minimum investment (E1)
Solid waste preliminary treatment (T2)	Local wisdom in solid waste management (S2)	Air pollution potential (odor and gas emission) (L2)	Availability of the regulation (K2)	Low operational and maintenance costs (E2)
Effectiveness of the treatment (T3)	Readiness of human resources in application of the technology (S3)	Air and soil pollution due leachate produced (L3)	The inter-stakeholder cooperation in a term of solid waste management (K3)	Improving direct benefits to society (E3)
Easy to operate (T4)	The absorption of labor (S4)	Aesthetics aspects/ the beauty of the environment (L4)		
Total processing time required (T5)	Community participation (S5)			

Based on the survey and observation results concerning the existing condition of solid waste management, the amount of solid waste generated reaches 12,554.38 liters/day with the most dominant types of waste consist of food scraps, paper, and plastic (the three of them are recyclable). On the other hand, the majority of the community in the study area (73%) prefers the individual solid waste management system directly on the source of waste. It implies the community's willingness to be directly involved in the process of solid waste management in their neighborhood. One of their local wisdom to use food scraps as animal feed (such as for pigs, dogs, and fish) also promotes this willingness.

Besides, the people in the study area mostly earn their living as farmers and traditional fishermen (51.75%) with an average income of less than Rp 500,000.00/month, so a convenient and inexpensive solid waste management system is required to avoid financial burdens to the society. Better yet, hopefully, it can increase the income of the community involved in the solid waste management process. On account of these data, a household-scale solid waste management concept focusing on recycling attempts is highly recommended. Other alternatives of management scheme that can be considered to be applied in Ifale Village, Yobeh Village, Putali

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Village, Atamali Village, and Asei Besar Village are (1) A household-scale solid waste management system combined with a waste bank concept; (2) Sorting, recycling, and incineration in an integrated waste treatment facility; and (3) An integrated solid waste treatment system initiated by the individual handling on a household scale.

After that, the criteria and sub-criteria in deliberating the waste management concept were determined. The selected criteria are technical aspects, social aspects, environmental aspects, institutional aspects, and economic aspects. The sub-criteria used in this study were specified based on the respondents' checklist as seen in Table 3.

The results of calculations using AHP method on the group of solid waste management stakeholders (local government, academics, community, and informal sector) indicate that the environmental aspect is a major priority (0.534 weight value) and has a crucial role in the determination of waste management concept, followed by the social aspects with a priority weight of 0.186 and technical aspects with a priority weight of 0.147 as shown in Table 4. This is consistent with the opinion of BPPT and IRIF (2000) about these three aspects in their article entitled Application of Urban Zero Waste Concept with Areas Scale: Community Empowerment through Small Recycling Industries.

Table 4 Priority weight of each criteria for overall waste management stakeholders

Criteria	Weight	Consistency Ratio (CR)
• Technical Aspects	0.147	0.061
• Social Aspects	0.186	
• Institutional Aspects	0.041	
• Environmental Aspects	0.534	
• Economic Aspects	0.092	

The environmental factor is a top priority that must be considered because it relates directly to the potential environmental impacts that may occur as a result of improperly treated solid waste (if the selected waste treatment plan does not work well). It can cause pollution of surface water and groundwater, odor and gas emissions, as well as the increased spreading of disease vectors in the study site. The value of consistency ratio is 0.061 or 6.1%, implying that the result

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of this calculation is quite consistent or within the limits of acceptance (≤ 0.1 or 10%).

Corresponding with the criteria assessment above, the global sub-criteria ranked as the highest priorities are also derived from the environmental aspects - air and soil pollution due to yielded leachate (0.30), air pollution potential (odor and gas emission) (0.12), and the transmission of disease vectors (0.07)-followed by other aspects of system operational convenience (T4) and community participation (S5) with a priority value of 0.07 for both (shown in Figure 3). It means that in general, all respondents consider these three components of environmental aspects as top priorities that need to be considered in the implementation of solid waste treatment.

As for the local sub-criteria, the highest priorities as shown in Figure 3 are (1) economic aspects with the sub-criteria priority of improving direct benefits to society (0.69); (2) institutional aspects with the sub-criteria priority of the cooperation between waste management stakeholders (0.63); (3) environmental aspects with the sub-criteria priority of water and soil pollution due to leachate (0.56); (4) technical aspects with the sub-criteria priority of operational easiness/convenience (0.45); and (5) social aspects with the sub-criteria priority of public participation (0.37). The result of this calculation is quite consistent or within the limits of acceptance because the obtained value of the consistency ratio is 0.048 or 4.8% (≤ 0.1 or 10%).

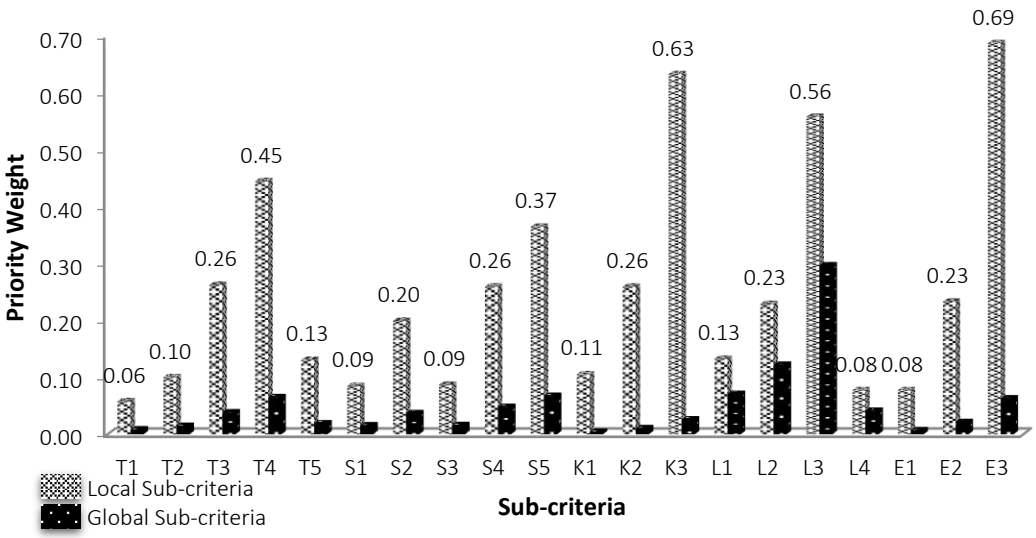

Figure 3 Sub-criteria's priority weight for overall stakeholders

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Based on the assessment of the overall stakeholders, the concept of integrated solid waste treatment initiated by the household-scale waste handling holds the highest priority weight of 2.05 as shown in Table 5 below. Hence, it is the most suitable solid waste management concept to be applied in Ifale Village, Yobeh Village, Putali Village, Atamali Village, and Asei Besar Village.

Table 5 Alternative solid waste management concept's priority weights for overall stakeholders

Alternative Solid Waste Management Concept	Weight	Consistency Ratio (CR)
Solid waste management on household scale which combined with an application of solid waste bank concept	1.14	0.028
Sorting, recycling and solid waste incineration in the integrated waste treatment facility	1.81	
Solid waste management concept in integrated solid waste treatment facility which starts with solid waste treatment on household scale	2.05	

Overall, the integrated solid waste management concept (starting from household-scale handling) has been chosen as the best alternative because it can meet many expectations from various points of view. On the technical stance, it can be synergized with the waste management program devised in Jayapura's spatial plan in 2008–2028. Based on the common characteristics of waste preliminary treatment which are easy to operate, effective, and does not require a long processing time, this management scheme is considered to be superior as well. This alternative is also good in minimizing the spread of disease vectors, more suitable with the public wishes and local wisdom, and able to absorb more labor compared with the other solid waste management concepts. The obtained value of consistency ratio is 0.028 or 2.8% (below the specified standard of ≤ 0.1 or 10%), implying that the result is representative.

4. CONCLUSION

The community in Ifale Village, Yobeh Village, Putali Village, Atamali Village, and Asei Besar Village aspires to establish an individual solid waste management system directly on the source of waste. Therefore, the recommended scheme that can be applied in the study site is the concept of solid waste management at the household scale focusing on the implementation of solid waste

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recycling treatment. Other alternatives that can be suggested to be applied in this area are (1) solid waste management on a household scale which combined with an application of waste bank; (2) sorting, recycling, and incineration in an integrated waste treatment facility; and (3) solid waste management concept in integrated treatment facility initiated by household-scale waste handlings.

The selected solid waste management concept is the integrated solid waste treatment facility (starting with household-scale handlings). It was chosen because it is better from the technical aspects such as easy to operate, able to meet the characteristics of the solid waste preliminary treatment, more effective, and it does not require a long processing time. It can also be synergized with the solid waste program devised in Jayapura's spatial plan in 2008–2028. Besides, this concept is also better in minimizing the spread of disease vectors, more suitable with the public wishes and local wisdom, and it can absorb more labor compared with the other alternatives of solid waste management concept.

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